The ENGLISH ELECTRIC JOURNAL

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The Malakand Power Station, showing Penstocks and Forebay.

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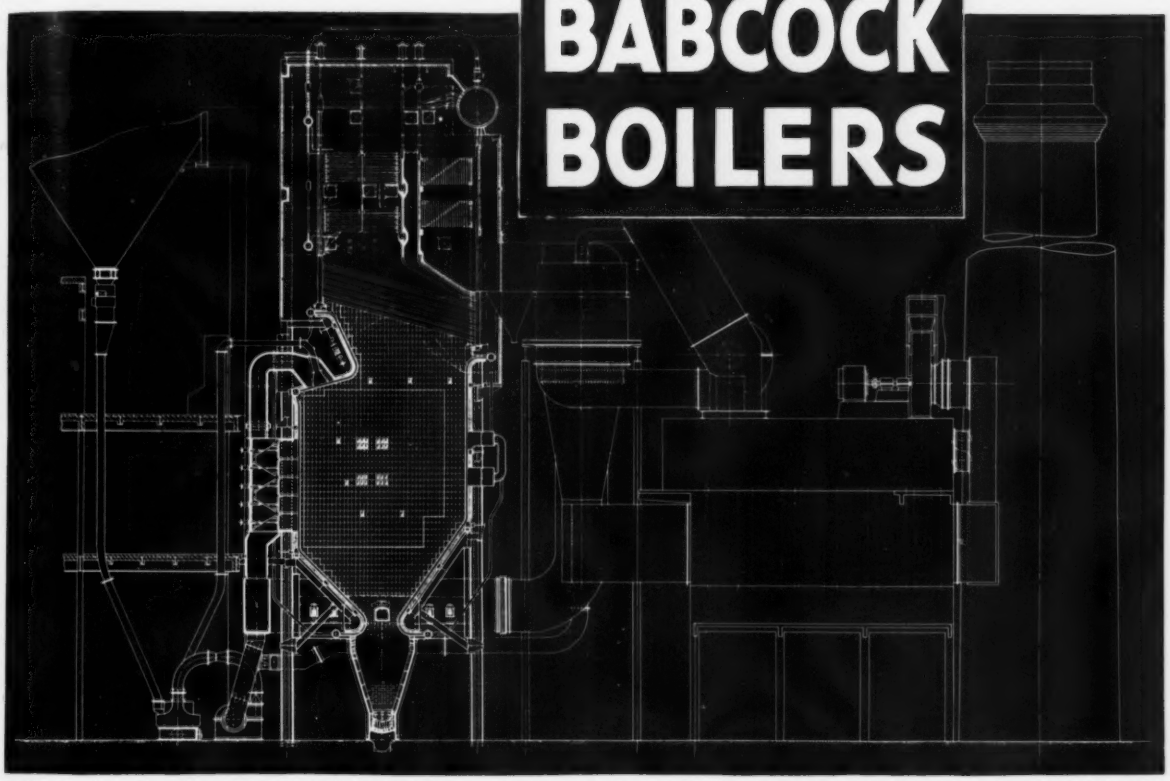

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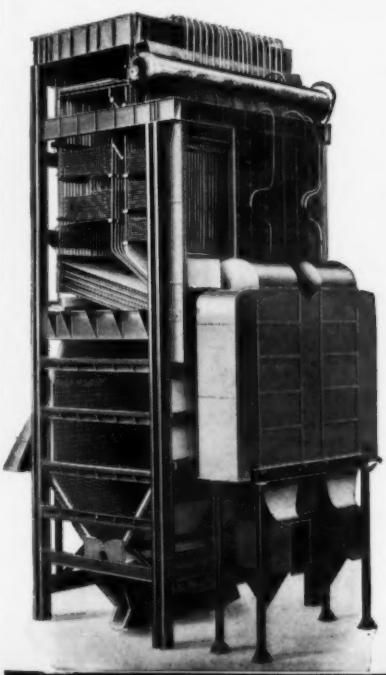

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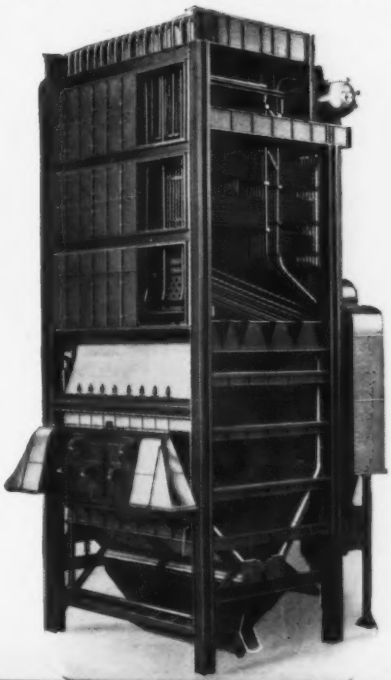

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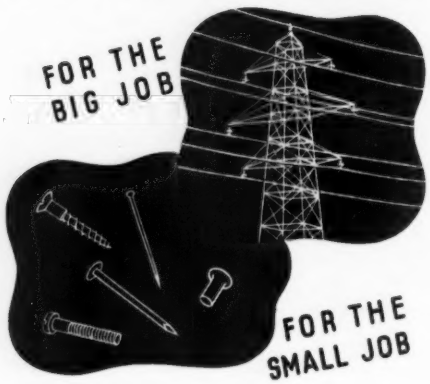

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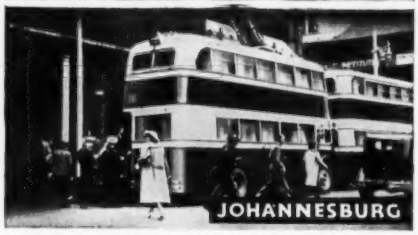

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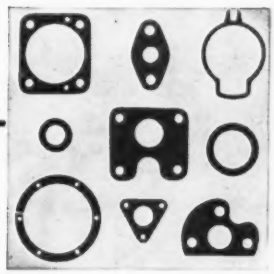

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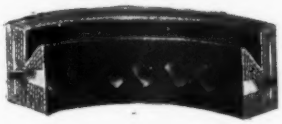

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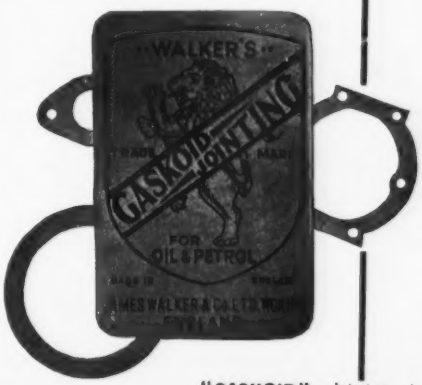

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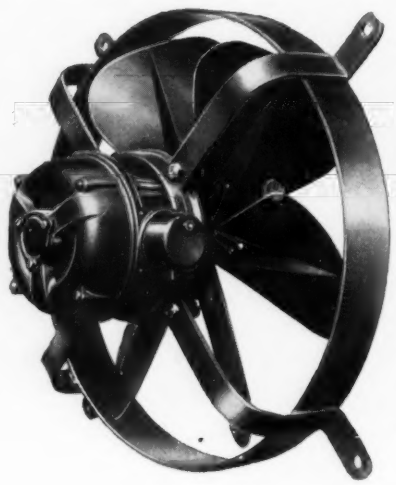

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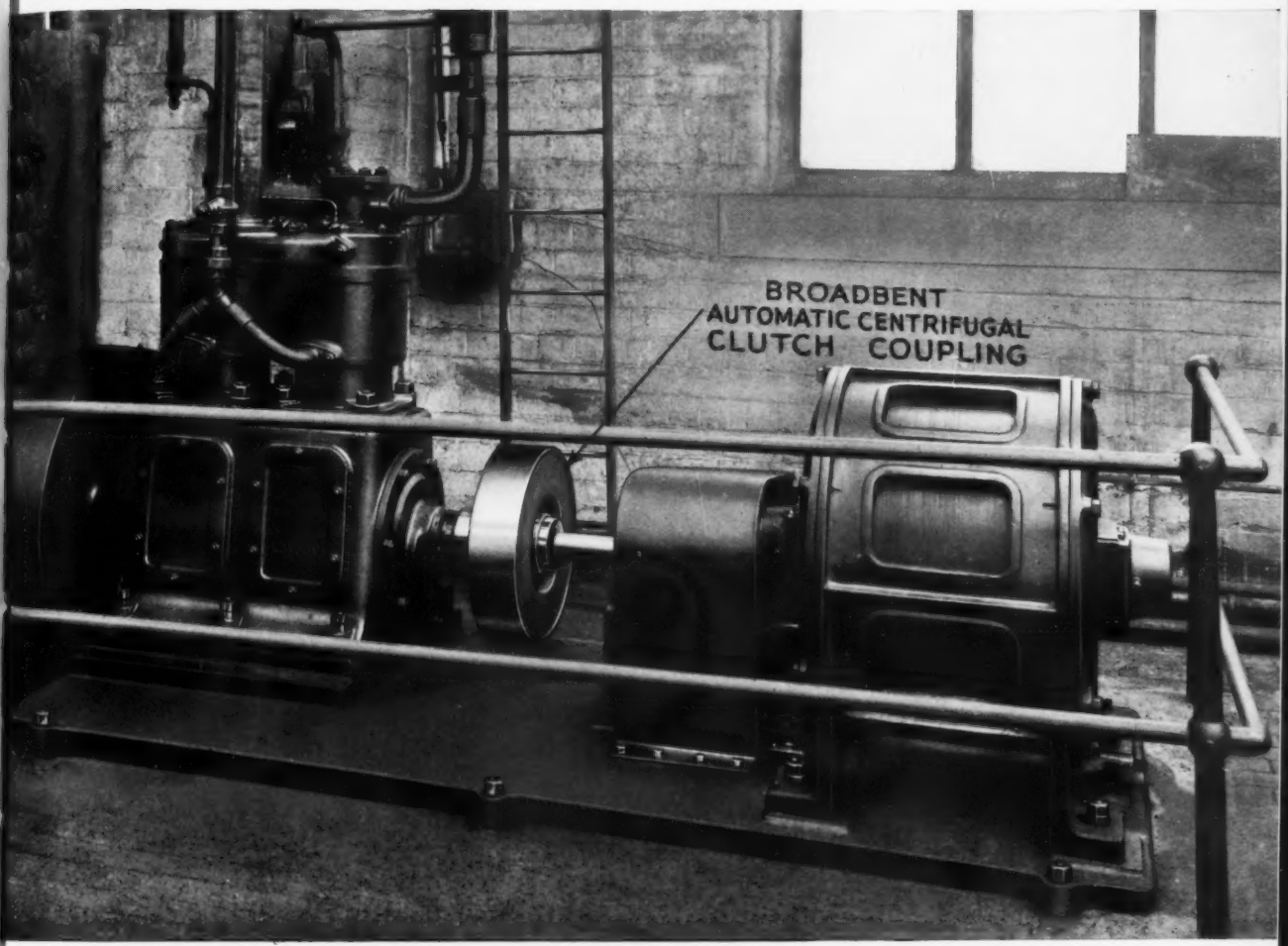

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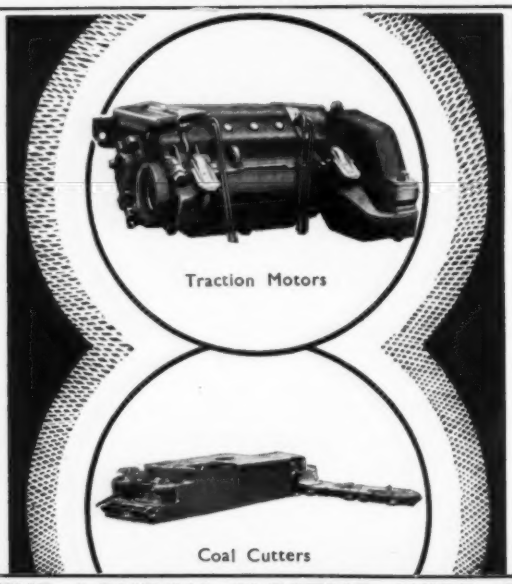

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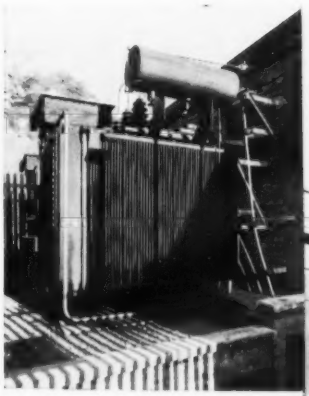

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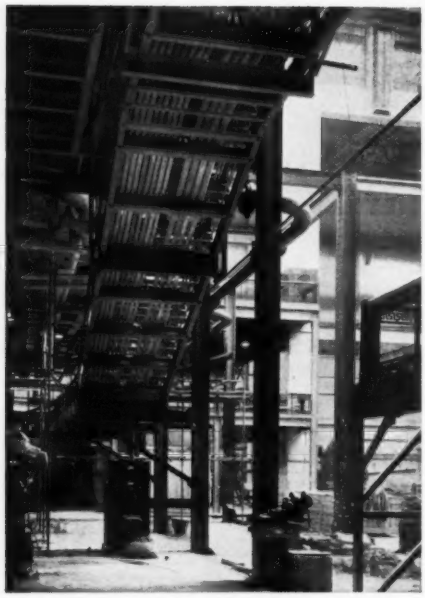

Underneath view of cables crossing turbine house at Battersea Generating Station.

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The English Electric Journal

Vol. IX. No. 3 SEPTEMBER/OCTOBER, 1938. One Shilling.

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All Communications respecting Editorial Contents should be addressed to The Editor, The English Electric Journal, The English Electric Company Limited, Stafford.

EDITORIAL.

In the first article in this issue of the Journal Mr. J. T. Moore contributes an interesting resumé of repeat orders for steam turbo-alternator plant received by the Company during the past two years. The sets described and illustrated vary in size from 800 kW. units for industrial purposes to 40,000 kW. 3,000 r.p.m. units for Electricity Supply Undertakings. The fact that these are all repeat orders is testimony to the effective service obtained from the plant originally supplied to the same purchasers, and it is to be noted that the article does not take into account the large number of other turbine plants supplied to new customers.

The article also deals with the progressive improvements that have been made in both the turbines and alternators as a result of the research and experimental

work which the Company are constantly carrying out. In this connection we would refer our readers to the last article in this issue entitled " New Developments in Low-Pressure Blading for Steam Turbines" by Mr. J. P. Chittenden. In this the Author deals with some of the problems met with in the design of the long blades at the low-pressure end of steam turbines of large output, so that the steam flow is guided with the maximum efficiency through these very long blades. In the article under review the Author briefly describes the " English Electric " Vortex-type blading which gives greatly improved efficiencies.

In the second article Mr. H. L. Bazalgette describes the Malakand Hydro-Electric Scheme located near the Khyber Pass in the North-West Frontier Province of India, a district made famous in the past by so many military campaigns. H.E. the Viceroy of India, the Marquess of Linlithgow, was present at the opening ceremony and started up the turbine plant. The successful completion of this contract is another instance of the Company's ability—aided by its overseas Organisation —to execute comprehensive hydro-electric contracts in any part of the world. The article is illustrated by some photographs of the plant, and of the surrounding country, which we think will be of interest.

30,000 kVA., 132 kV./33 kV. Transformer leaving the Company's Stafford Works for the Central Electricity Board's Substation, Oxford.

"English Electric" Steam Turbo-Alternator Plant—Recent Repeat Orders.

By J. T. MOORE, B.Sc., A.R.T.C., A.M.Inst.C.E., A.M.I.Mar.E., Steam Turbine Dept.

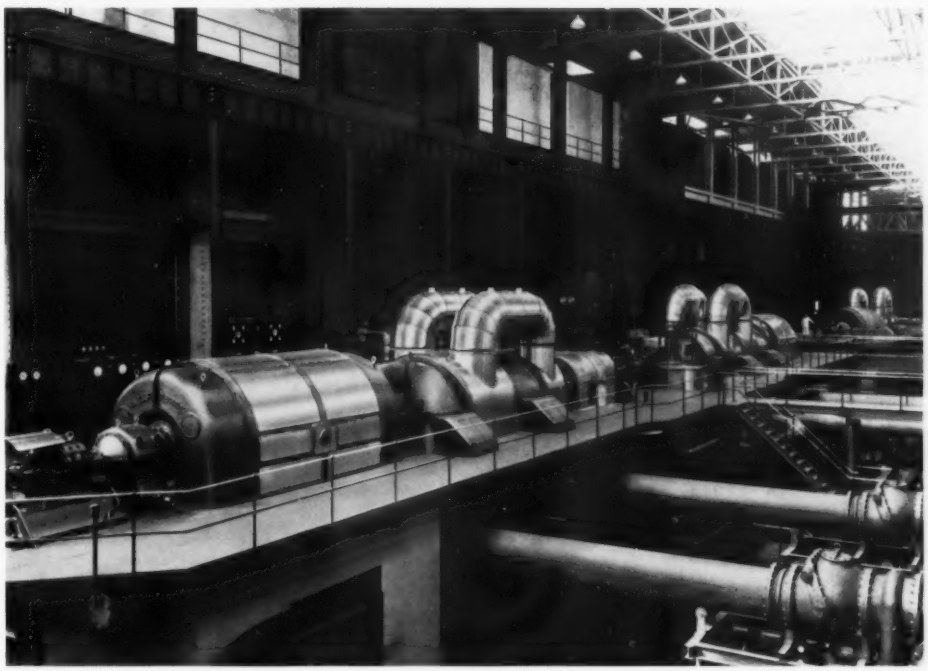


Fig. 1.—One 25,000 kW. and two 30,000 kW. three-cylinder Turbo-alternator sets at the Blackburn Meadows Power Station of Sheffield Corporation.

It is said that a progressive outlook is the life-blood of an industry. This is certainly true of the electrical industry, which has progressed in a spectacular manner since the beginning of the present century, but inherent to the progress of an industry as a whole is the progress by research and experiment which must take place continuously in the design and construction of its manufactures, and this is especially the case on the heavy engineering side of the electrical industry. It has been only by constant research and experiment, however, that the advances of to-day have been made possible, and it will be only continued work on these lines which will produce the advances of to-morrow.

The English Electric Company has always taken a leading part in the progressive development of the electrical industry, and in no sphere of its activities more so than on power station equipment. Progress involving changes in design, however, must be soundly conceived, and it will be appreciated that this is of the utmost importance in regard to electrical generating plant, where the diverse factors to be dealt with, both mechanical and electrical, call for the most careful consideration of each new departure from previous practice. It is therefore of particular interest to note the large number of repeat orders which have been received within the last two years for steam turbo-alternator

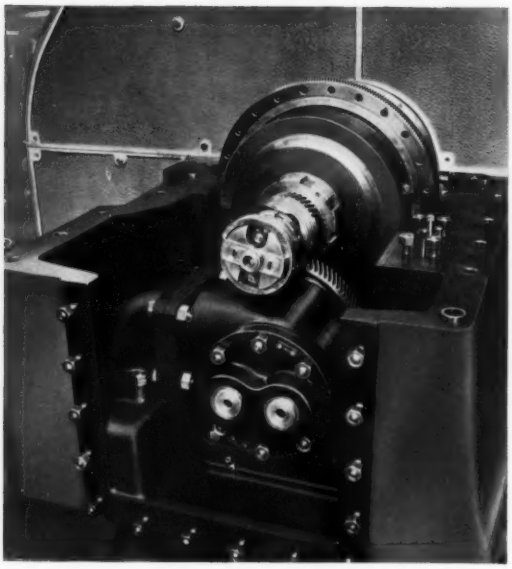


Fig. 2.—Latest type Main Gear-type Oil Pump, with single helical gear drive.

plant for service both in this country and overseas.

The sizes of the sets vary from 1,000 kW. up to 40,000 kW. and the large range covered is a tribute to the maintained quality and design of the steam turbines, alternators, condensers and feed heating plants manufactured by the Company. It will be generally acknowledged that repeat orders in themselves are proof of the satisfactory design and service of the plants previously supplied to the purchasers.

The experience of the Company goes back to the beginning of the present century under the constituent companies, and progress has been steady and sustained since that date. The Company was one of the first in this country to manufacture 3,000 r.p.m. steam turbines, the first to construct in this country a 20,000 kW., 3,000 r.p.m., multi-cylinder impulse reaction turbine, the first to supply a 30,000 kW., 3,000 r.p.m. steam turbo-alternator set for this country, and is now completing the first two 40,000 kW., 3,000 r.p.m. steam turbo-alternator sets for installation in this country. A formidable record, and one of which to be justly proud, in view of the following recent repeat orders for steam turbo-alternator sets.

Sheffield Corporation.

Since the construction of the first power station in Sheffield, twelve "English Electric" turbo-alternator sets have been supplied for the Sheffield Corporation, amounting to a total capacity of 172,875 kW. Seven of these sets have been supplied for the Neepsend Station, two for the original Blackburn Meadows Station, and the last three, shown in Fig. 1, are installed in the new Blackburn Meadows Station. The first of these three, of 25,000 kW. capacity, was installed in 1932, the second, of 30,000 kW. capacity, in 1935, and the third, a repeat of the second, was ordered in 1936, and put into service a few months ago. All three sets have turbines of the three-cylinder impulse reaction type, are designed for initial steam conditions of 570 lbs./sq. inch, 825 deg. F. with a vacuum of 28¼ inches, and run at a speed of 3,000 r.p.m. The alternators are designed for 11,400 volts. The two 30,000 kW. turbines are each fitted with the latest type of main gear oil pump, as illustrated in Fig. 2, driven from the turbine shaft through a single helical gear, only the vertical governor spindle now being driven through worm gearing. With this design, standardised for all large turbines, the pump can be made of any desired capacity without the previous limitations in pump loading due to the worm gear drive. Details of the pump are also illustrated in Fig. 19.

Huddersfield Corporation.

A 20,000 kW. turbo-alternator set ordered for the extension of the Huddersfield Corporation Power Station in the latter half of 1936, and at present being erected on site, brought the total number of turbo-alternator sets supplied for Huddersfield to nine, with a total capacity of 60,800 kW. All the sets in the Station are of "English Electric" manufacture, the last unit having a turbine of the two-cylinder impulse-reaction type designed for steam at 350 lbs./sq. inch, 750 deg. F. and a vacuum of 28½ inches. The general design of the turbine follows that of the largest sets, and it is interesting to note the very similar design, as illustrated in Fig. 3,

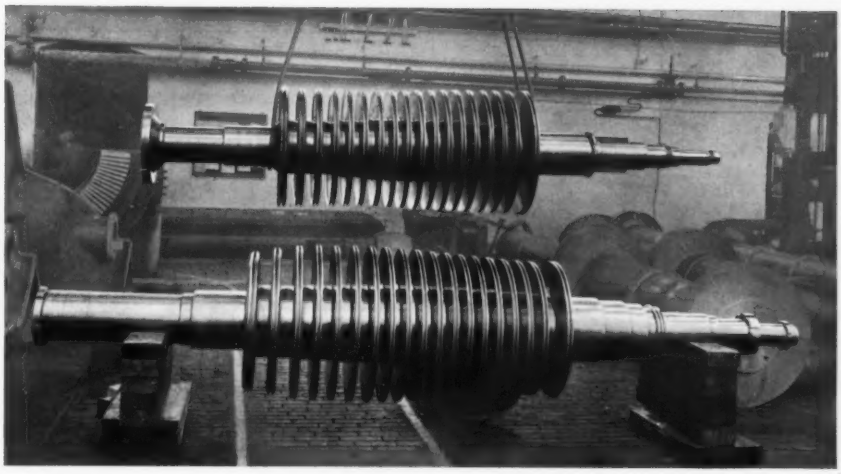


Fig. 3.—The H.P. rotor forging for a 20,000 kW. two-cylinder turbine for Huddersfield Corporation, compared with H.P. rotor forging for 40,000 kW. two-cylinder turbine for the Ferrybridge Power Station of the Yorkshire Electric Power Company.

between the H.P. rotor for the 20,000 kW. turbine for Huddersfield, and the corresponding H.P. rotor of the 40,000 kW. turbine for Ferrybridge, both machines being designed for a speed of 3,000 r.p.m. The internal design of the Huddersfield turbine also incorporates many features previously used only on the largest machines, such as the helical gear drive of the main oil pump, which is illustrated in Fig. 2.

Aberdeen Corporation.

The last set ordered for the Aberdeen Corporation Power Station, in the latter half of 1936, brought the number of " English Electric " units up to five, with a total capacity of 42,250 kW. All the turbines supplied, although of medium capacity, have very large low-pressure ends on account of the very high vacua encountered over most of the year, and on the last two machines supplied, the last two rows of the low-pressure rotor have special side entry blading on account of the high blade-tip speed. This special type of blade fixing has previously been fully described in the article* which appeared in a recent issue of this Journal. The illustration in Fig. 5 shows the low-pressure rotor for the latest set for Aberdeen in the dynamic balancing machine at Rugby Works. This set, at present in course of erection, has a capacity of 15,000 kW., and the turbine is of the two-cylinder impulse-reaction type designed for steam conditions of 240 lbs./sq. inch, 630 deg. F., and a vacuum of 29.1 inches at the maximum rating.

Fig. 4.—Spherically seated combined Thrust and Journal Bearing for large multi-cylinder turbines.

* *See F. J. Cowlin, "The 'English Electric' Optimum Blade for Steam Turbines of Large Outputs," The English Electric Journal, December, 1937, (Vol. VIII, No. 8.).*

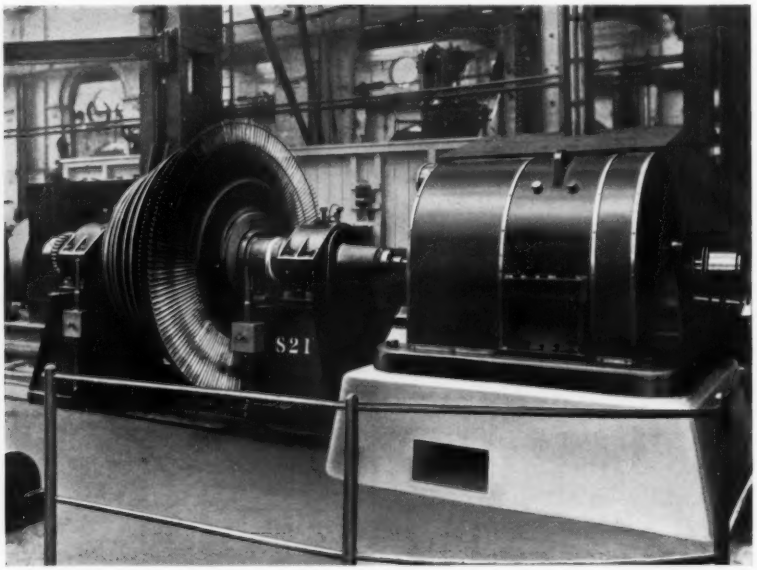


Fig. 5.—The L.P. rotor of a 15,000 kW. turbine for Aberdeen Corporation, during dynamic balancing.

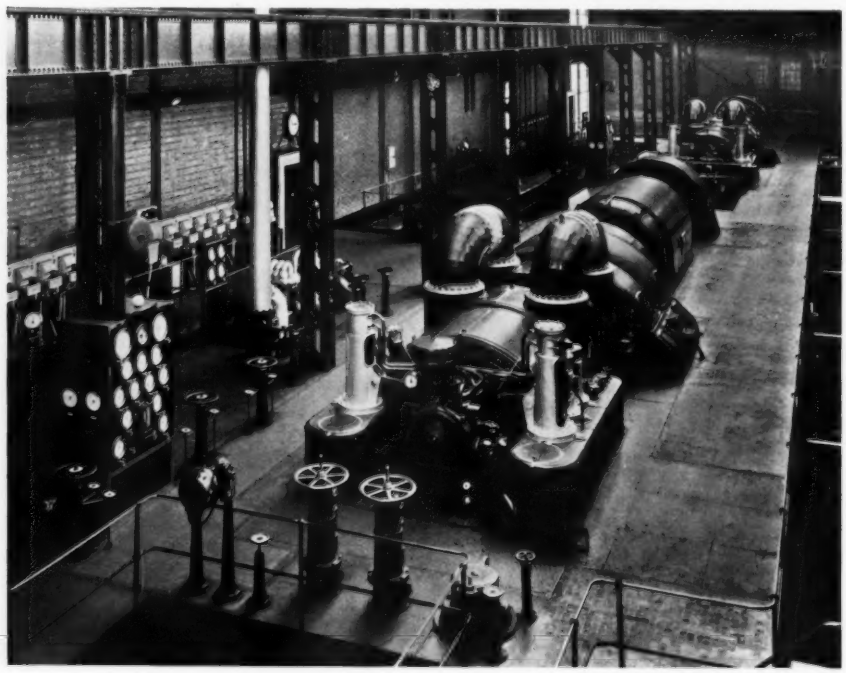


Fig. 6.—Two, two-cylinder 30,000 kW. turbo-alternator sets at the Thornhill Power Station of The Yorkshire Electric Power Company.

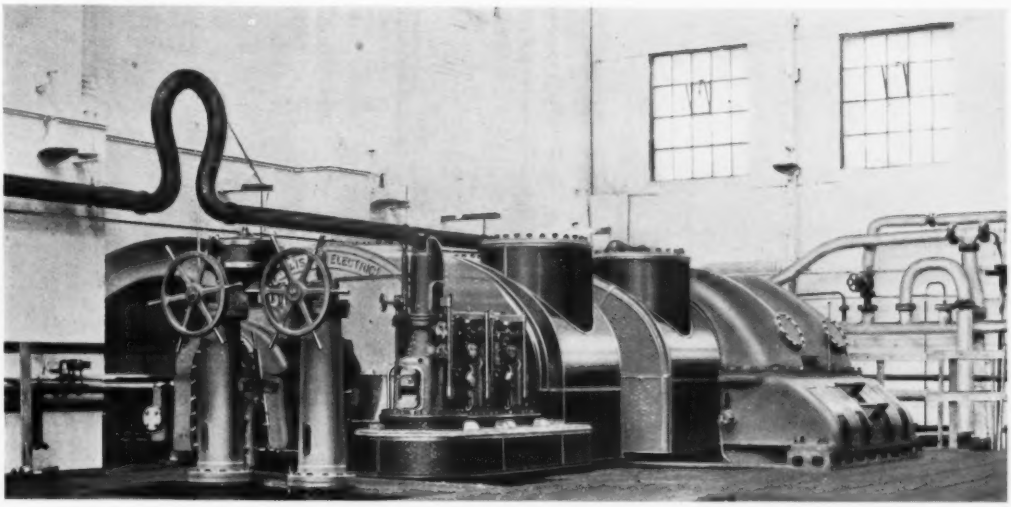


Fig. 7.—One of the two 40,000 kW. two-cylinder turbines for the Ferrybridge Power Station of the Yorkshire Electric Power Company, on the test bed at Rugby Works.

YORKSHIRE ELECTRIC POWER CO.

Following the installation of two 30,000 kW. turbo-alternator sets, illustrated in Fig. 6, in the Thornhill Power Station of the Yorkshire Electric Power Co., two 40,000 kW. turbo-alternator sets of similar design were ordered at the end of 1936 for the Ferrybridge Power Station. At the beginning of this year a further four turbines, each of 1,000 H.P. capacity, 6,000 r.p.m., were ordered for driving the boiler feed pumps in the new extension at Ferrybridge, and these, with the sets previously supplied for the Barugh Power Station, brings the number of machines supplied or on order up to ten, with a corresponding capacity of 155,484 kW.

The two 40,000 kW. turbo-alternator sets are designed for steam conditions of 600 lbs./sq. inch, 850 deg. F. with a vacuum of 28.8 inches, and the alternators for a pressure of 10,500 volts. Fig. 7 is an illustration of one of the 40,000 kW. turbines on the test-bed at the Company's Rugby Works. The turbine is of the two-cylinder type with a single-flow impulse H.P. cylinder and an inwards double-flow

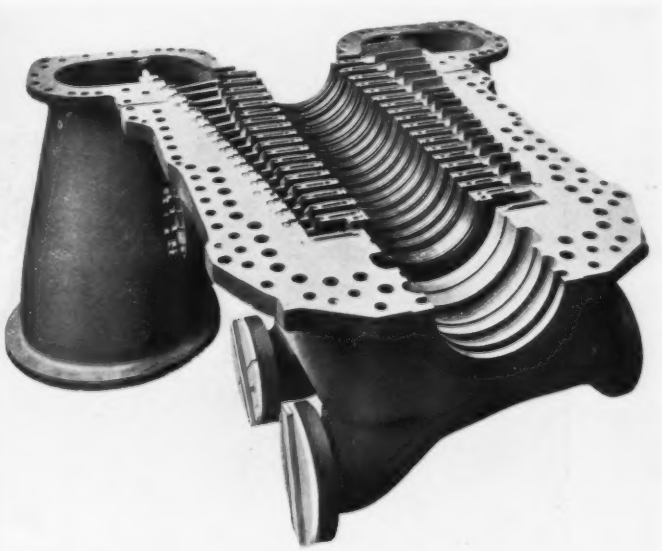


Fig. 8.—Half of the H.P. Casing with Steel Diaphragm in position, of one of the 40,000 kW. two-cylinder turbines for Ferrybridge.

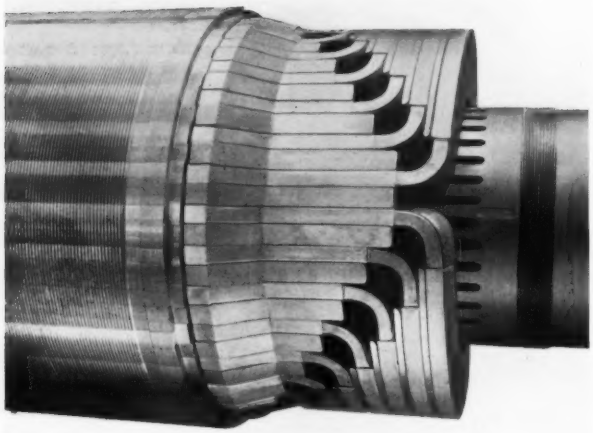


Fig. 9.—Rotor End-Winding of large Turbo-alternator, prior to mounting of rotor end-bells.

reaction L.P. cylinder. All the diaphragms in the H.P. cylinder are of steel and of the " built-up " type which has been used by the Company for many years with excellent results. The illustration in Fig. 8 shows one half of the H.P. casing with the all-steel diaphragms in position. It will be noticed that there is no break of continuity in the diaphragm nozzles at the horizontal joint of the casing, the nozzles in each half of the diaphragms intermeshing with the nozzles in the corresponding half, thus giving a continuous discharge after each diaphragm, without breaks to set up vibration in the rotating blades. The main oil pump drive and the thrust bearings are of the latest design as illustrated in Figs. 2, 4 and 19.

The design of the alternator follows standard practice, with the stator winding of the basket type, and the rotor machined from a solid Siemens-Martin steel forging. The special method of bracing the rotor end windings which is used on all large turbo-alternators of 30,000 kW. and over is illustrated in Fig. 9, from which it will be seen that the end-windings are closely packed with machined and fitted light alloy spacers and the end-windings further protected with light alloy shields prior to the mounting of the rotor end-bells.

STEWARTS AND LLOYDS, LTD., CORBY.

A 2,500 kW. turbo-alternator set was supplied in 1935 for the Corby Works of Messrs. Stewarts and Lloyds, Ltd., and in 1936, a further set of 7,500 kW. capacity was ordered. This set was put into service last year, and operates on steam conditions of 350 lbs./sq. in., 600 deg. F., with a vacuum of 28 inches. The alternator is designed

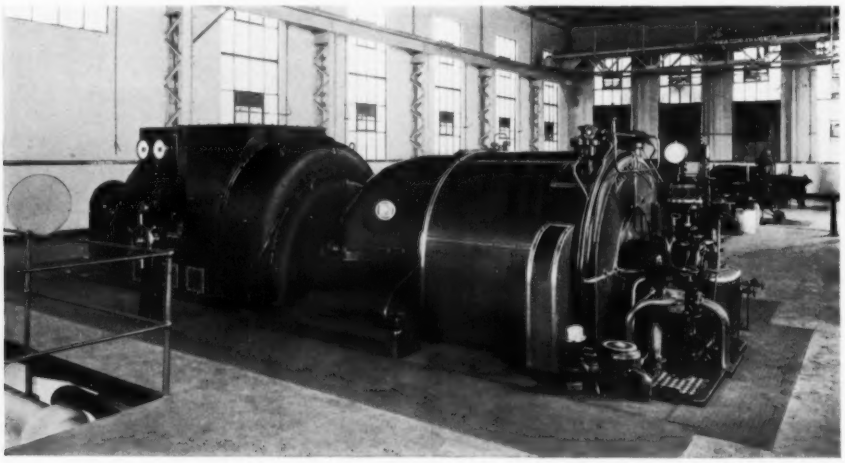


Fig. 10.—7,500 kW. Turbo-alternator set at the Corby Works of Stewarts and Lloyds, Ltd.

for a pressure of 11,000 volts, and is of the turbo-type, direct-coupled to the 3,000 r.p.m. turbine, as shown in the illustration of the unit in Fig. 10.

DUNDEE CORPORATION.

In the Dudhope Crescent Station of the Dundee Corporation are installed several of the original Willans Central Valve steam engine-driven generating sets, and although retained solely as standby plant, they are even now quite ready for operation if necessary. Following the Willans engines, seven turbo-alternator sets have been supplied for the Carolina Port Station, the most recent being a 15,625 kW. two-cylinder unit which is illustrated in Fig. 11. At the end of 1937 a further set of 30,000 kW. capacity was ordered for the Carolina Port Station, making a total of eight turbo-alternator sets with an aggregate capacity of 75,125 kW. This last mentioned set is being designed for steam conditions of 325 lbs./sq. in., 750 deg. F. with a vacuum of 29 inches at the maximum rating of 30,000 kW. The turbine is of the two-cylinder impulse-reaction type, and drives in tandem a 3,000 r.p.m. 33,000-volt main alternator of 28,500 kW. and a 3,000 r.p.m. 440-volt house alternator of 1,500 kW. The general design of the turbine will be similar to those shown in Figs. 6 and 7, and, as now standardised on all "English Electric" multi-cylinder turbines, the last stages of rotating blading in the low-pressure cylinder will be fitted with specially hardened steel shielding, as illustrated in Fig. 12, to reduce to a minimum the erosion of the low-pressure blading due to the moisture in the steam in the L.P. stages. This subject has been fully described in a recent article* in this journal. On account of the high vacua encountered at Dundee, the steam at the exhaust contains a comparatively large percentage of moisture, and it is of interest to record that shielding fitted about five years ago to the last low-pressure stages on the 15,625 kW. turbine illustrated in Fig. 11, continues to show no appreciable wear.

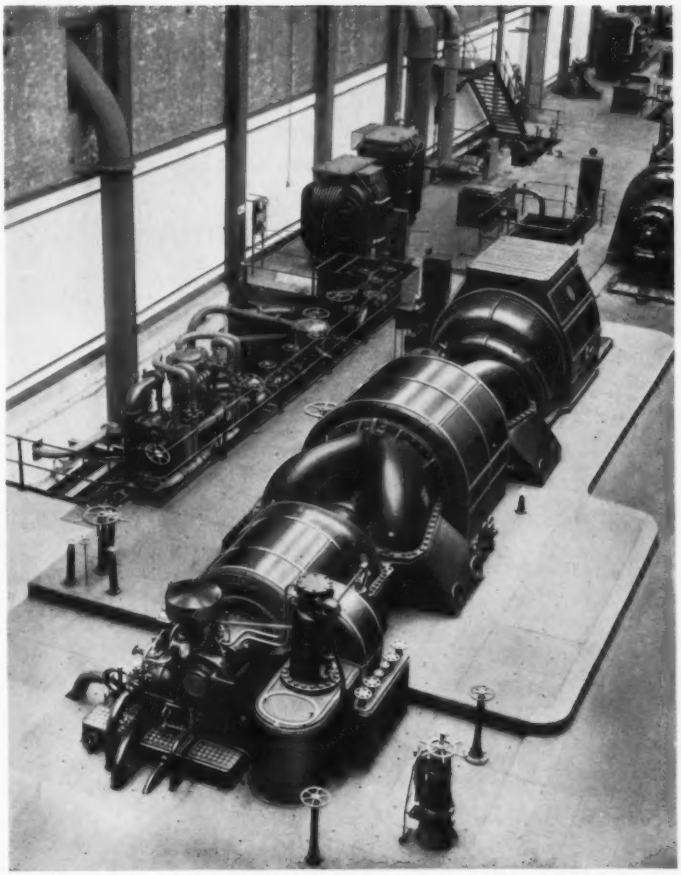


Fig. 11.—A 15,625 kW. two-cylinder Turbo-alternator set at the Carolina Port Power Station, Dundee.

STOURPORT POWER STATION.

In 1936 an order was received from Messrs.

* *See L. C. Hookins, "Wetness in Steam Turbines." The English Electric Journal, July, 1938 (Vol IX, No. 2).*

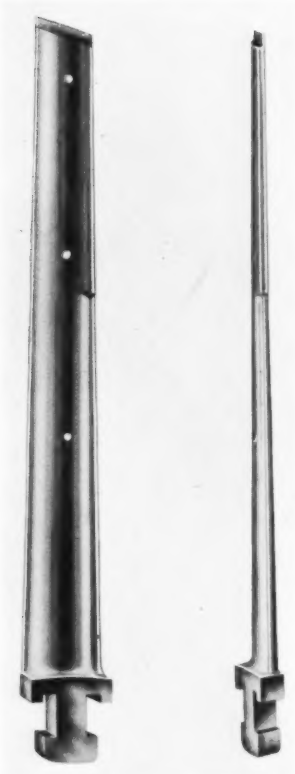


Fig. 12.—Large low-pressure blades fitted with anti-erosion hardened steel shielding.

Edmundsons Electricity Corporation, Ltd., for two 30,000 kW. turbo-alternator sets for the Stourport Power Station of the Shropshire, Worcestershire and Staffordshire Electric Power Co., and these units, which are in commercial service, are illustrated in Fig. 13. This year a third set of 30,000 kW. capacity has been ordered for the same station. The design of all the turbo-alternator sets is identical, each incorporating a 3,000 r.p.m. two-cylinder impulse-reaction turbine designed for steam at 625 lbs./sq. in., 825 deg. F. with a vacuum of 29 inches at M.C.R., and an 11,000-volt alternator, with the necessary condensing and feed heating plant. The governing valve gear, illustrated in Fig. 14, is of the latest improved form with reversed oil servo-motor pistons on all the governing valves so that any leakage from the oil gland, which is now on top, cannot come in contact with the valve spindle and become a possible source of trouble from carbonisation. Equally important is the resultant considerable reduction in the fire risk, and it may be mentioned in this connection that the only oil pipes containing oil under comparatively high pressure are those shown connecting to the oil servo-motor cylinders and they are of solid drawn steel of heavy section.

The turbines, being of the inwards double-flow L.P. design, exhaust into single-shell condensers having fabricated steel shells and cast iron divided water boxes, as illustrated in Fig. 15, from which can also be seen the hinge-gear for the removal of the water box end-covers. The arrangement of the condenser is also clearly shown in Fig. 13.

Bolton Corporation.

At the time of its installation in 1924, the last turbo-alternator set of 15,625 kW capacity supplied for the Back o' th' Bank Power Station, Bolton, was one of the largest single-cylinder 3,000 r.p.m. turbines in operation in this country. This set, which has given extremely good service is illustrated in Fig. 16 and with the 31,250 kW. turbo-alternator set ordered at the end of 1937, brings the total capacity of generating plant supplied and on order for the Back o' th' Bank Station to 54,375 kW., with three units. The 31,250 kW set will have a two-cylinder turbine with a single-flow H.P. cylinder of the impulse type and an outwards double-flow twin exhaust L.P. cylinder of the reaction type, exhausting into twin condensers. The steam conditions are 400 lbs./sq. in., 800 deg. F. with a vacuum of 28½ inches. The electrical end of the unit incorporates, in addition to a 30,000 kW., 6,600-volt main alternator, a 1,250 kW. direct-coupled 3,000 r.p.m. house alternator for station auxiliaries supply at 440 volts. Both alternators will have fabricated steel casings. Fig. 17 shows the fabricated frame of a similar 30,000 kW., 6,600-volt alternator stator in course of manufacture, from which the general design and method of bracing can be clearly seen.

Hayle Power Station.

The first turbo-alternator set supplied to Messrs.

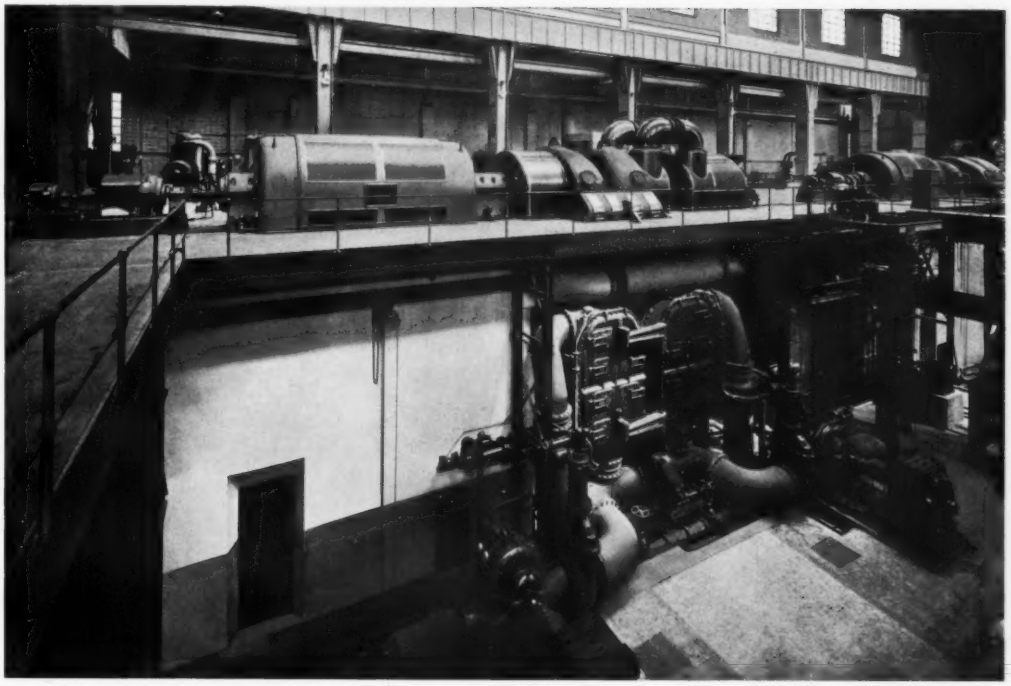


Fig. 13.—Two 30,000 kW. two-cylinder Turbo-alternator sets at the Stourport Power Station of the Shropshire, Worcestershire and Staffordshire Electric Power Company.

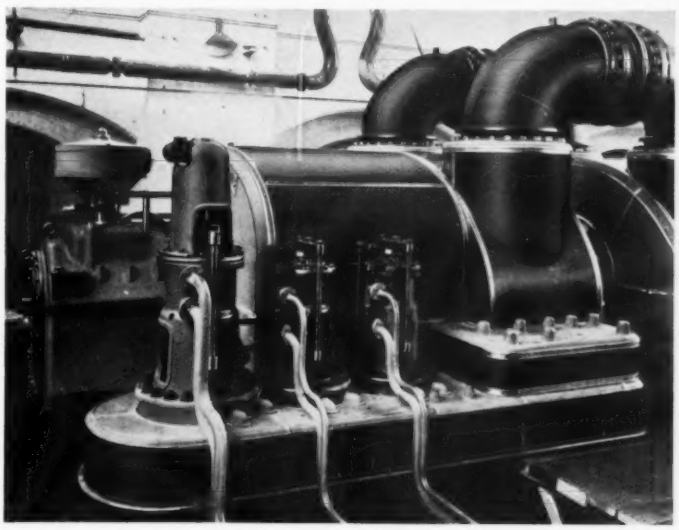


Fig. 14.—The Governing Valve Gear on the 30,000 kW. Turbines for Stourport.

Edmundsons Electricity Corporation for the Hayle Power Station of the Cornwall Electric Power Co. was of 10,000 kW. capacity with a turbine of the two-cylinder impulse reaction type, and last year a further turbo-alternator set of similar design but having a capacity of 15,000 kW. was ordered for the same station. This unit is designed for steam conditions of 235 lbs./sq. in., 730 deg. F. with a vacuum of 28¾ inches, and an alternator voltage of 11,000 volts. The two-cylinder turbine in course of completion at the Company's Rugby Works is illustrated in Fig. 18, and although of medium output, the main gear oil pump, details of which

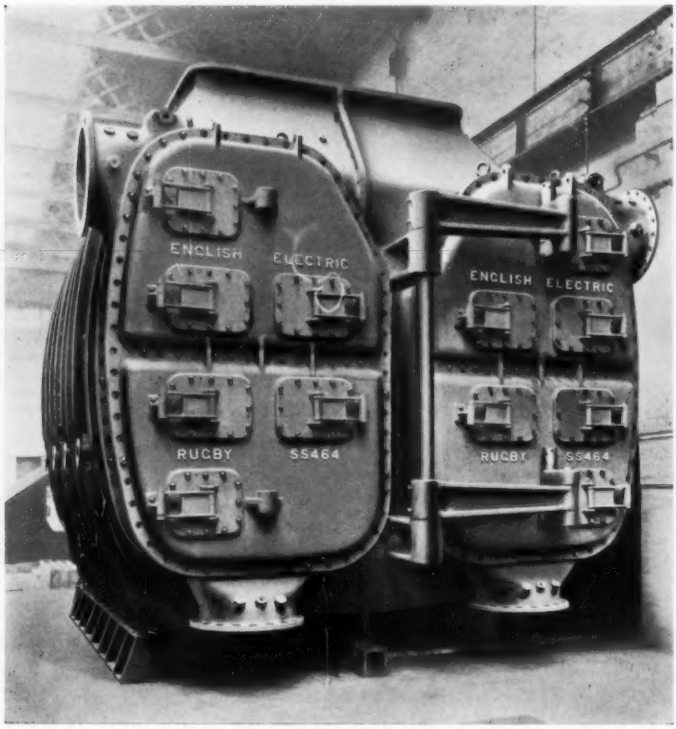


Fig. 15.—Single-shell Condenser with divided waterways, for 30,000 kW. Turbine for the Stourport Power Station of the Shropshire, Worcestershire and Staffordshire Electric Power Company.

are shown in Fig. 19, is of the latest type with single-helical gear drive from the shaft.

Anglo-Iranian Oil Co., Ltd.

With the order in 1937 for two 22,500 kW. turbo-alternator sets for their Abadan Power Station, Iran (Persia), a total of four turbo-alternator sets have been supplied to the Anglo-Iranian Oil Co., Ltd., for this station, and with the two supplied for the Tembi Station the corresponding total capacity becomes 67,500 kW. The latest two sets are duplicates, and incorporate turbines very similar to the two-cylinder turbine illustrated in Fig. 18. The operating steam conditions are 200 lbs./sq. in., 750 deg. F., with a vacuum of 28 inches at M.C.R. The condenser shells, as illustrated in Fig. 20, are of fabricated steel construction, now standard for all condensers.

Cawnpore Electric Supply Co., Ltd.

This year the order was received from the Cawnpore Electric Supply Co., Ltd., for a duplicate of the 15,000 kW. two-cylinder turbo-alternator set supplied last year for their Power Station at Cawnpore, India, and a photograph of which unit during completion of erection at site is shown in Fig. 21. This set operates on steam conditions of 420 lbs./sq. in., 780 deg. F. with a vacuum of 28 inches and the repeat unit will also be designed for the same conditions. The turbines are of the standard impulse-reaction type with single-flow L.P. cylinder, as illustrated in Fig. 22, which shows the first 15,000 kW. turbine in course of erection at Rugby Works for steaming before despatch.

The Cawnpore Power Station, like the Carolina Port Power Station of Dundee Corporation, and also the Huddersfield Corporation Power Station, contains all "English Electric" turbo-generating plant, and this latest order brings the number of turbo-alternators supplied and on order for this Station to ten, with a total capacity of 84,750 kW. Included in this number is a 3,750 kW. "superposed" turbine supplied in 1937, taking steam at 420 lbs./sq. inch, 780 deg. F. and exhausting at 180 lbs./sq. inch into the low-pressure steam range serving the original turbo-alternator sets in the station. The addition of this "superposed," or "topping" unit will enable the overall efficiency of the station to be very considerably improved.

Associated Portland Cement Manufacturers, Ltd.

Following on the supply a few years ago of a 4,500 kW. turbo-alternator set for the Japla,

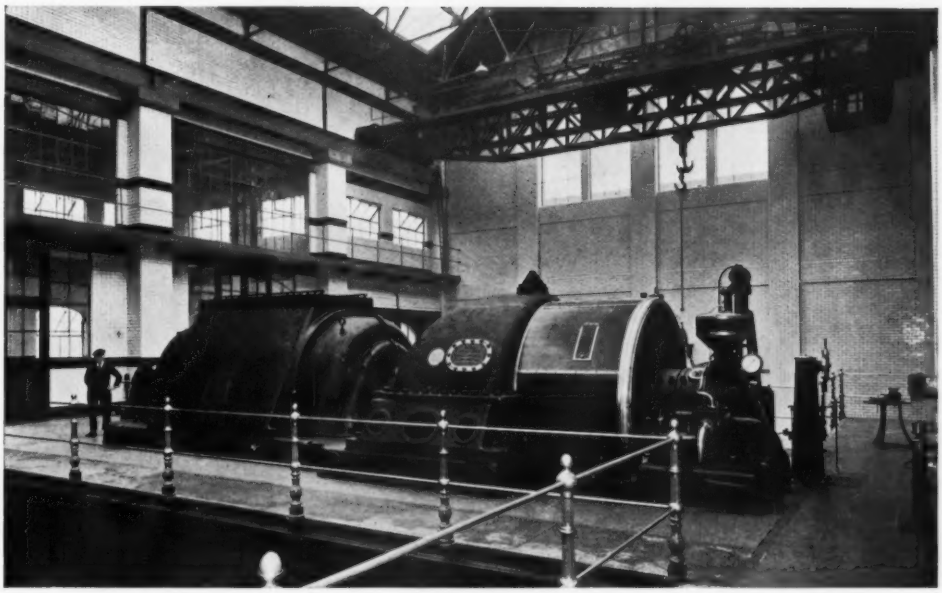


Fig. 16.— 15,625 kW. Turbo-alternator set at the Back o' th' Bank Power Station, Bolton.

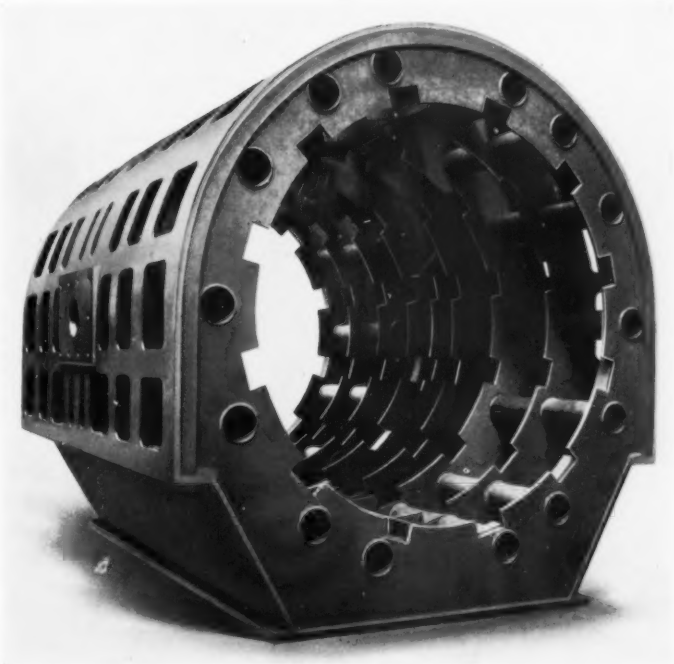


Fig. 17.—Fabricated Stator Casing of Turbo-alternator for 30,000 kW., 6,600 volts.

India, Works of the Associated Portland Cement Manufacturers Ltd., a further unit of 7,500 kW. ordered in 1937, has been despatched to site. The turbine is of the single-cylinder impulse type designed for steam conditions of 190 lbs./sq. inch, 625 deg. F. and a vacuum of 27·6 inches. The turbine runs at a speed of 3,000 r.p.m. with a direct-coupled 3,300-volt alternator provided with closed circuit ventilation. The unit is of similar general design to the 7,500 kW. set shown in Fig. 10.

CITY OF JODHPUR, INDIA.

A 1,250 kW, 7,000/1,500 r.p.m. non-basement type geared steam turbo-alternator set was recently completed for the City of Jodhpur, India, and is illustrated in Fig. 23, which shows the unit after completion of steaming tests at Works, with the alternator rotor coupled to the turbine. This order followed the successful

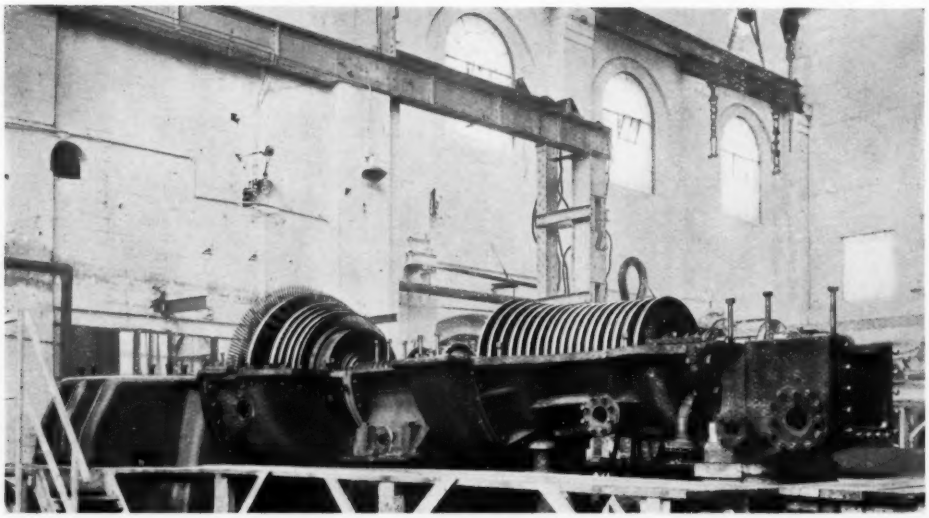


Fig. 18.—15,000 kW. two-cylinder Turbine for the Hayle Power Station of The Cornwall Electric Power Company, in course of erection at Rugby Works.

results obtained with a 1,250 kW. basement type turbo-alternator set supplied in 1928 for the same station. The change with the latest set, to a non-basement arrangement was made on account of the higher efficiency obtainable with this modern design of small turbine unit, and on account of the saving in cost of foundations. The turbines of both units are designed for steam conditions of 150 lbs./sq. inch, 466 deg. F. total temperature, exhausting to a vacuum of 27 inches; the alternators are designed for 3,300 volts.

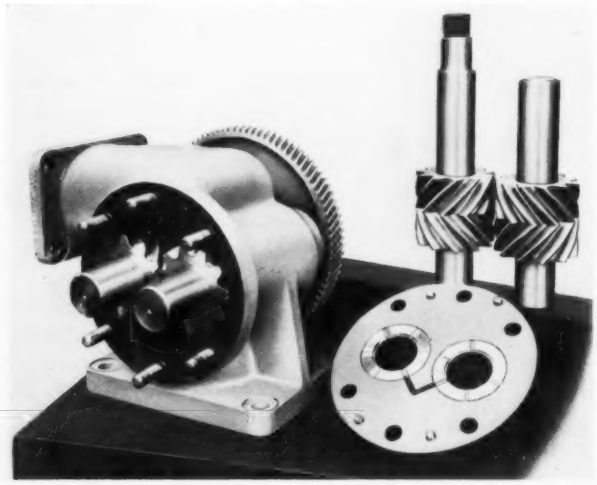


Fig. 19.—Principal components of the latest type main gear-type Oil Pump.

British Sugar Corporation, Ltd.

In 1936 orders were received from The British Sugar Corporation, Ltd., for a 1,300 kW. back pressure steam turbo-alternator set for their Wissington Works, and a similar unit of 800 kW. capacity for their Kidderminster Works. The latter unit is illustrated in Fig. 24, and comprises an 800 kW., 6,000 r.p.m. back-pressure turbine designed for steam at 165 lbs./sq. inch, 463 deg. F., with a back pressure of 20 lbs./sq. inch, driving through gearing at 1,500 r.p.m. a 3-phase, 440-volt alternator. These sets were put into commission last year and at the beginning of the current year further orders were received for a 2,000 kW. back-pressure set for the Ely Works, and a 1,250 kW. back-pressure set for the Kelham Works. In both cases the turbines are designed for steam at 160 lbs./sq. inch, 510 deg. F. with a back pressure of 30 lbs./sq. inch. The

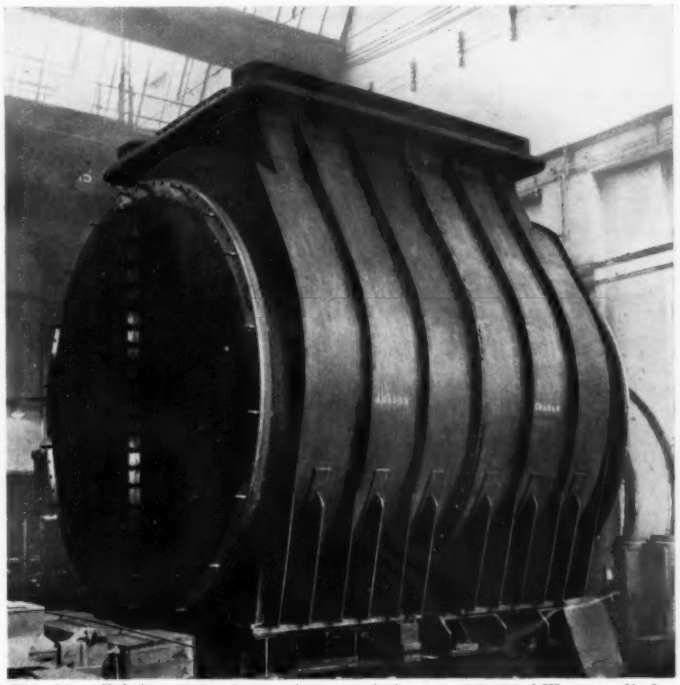


Fig. 20.—Fabricated Condenser for one of the two 22,500 kW. two-cylinder Turbo-alternator sets for the Anglo-Iranian Oil Company, Ltd., in course of completion at Rugby Works.

set for Ely was finished at the Works last July, the set for Kelham in August, and both sets are now erected on site.

The above orders, with an 800 kW. set previously supplied for the Ely Works, make a total of 6,150 kW. of small back-pressure turbo-alternator sets supplied for the British Sugar Corporation.

SLOUGH TRADING ESTATES, LTD.

Following the installation in 1933 of a 7,500 kW. turbo-alternator set in the Power Station of Slough Trading Estates, Ltd., a 2,000 kW. high - pressure back-pressure "topping" unit was supplied in 1937. This set, illustrated in Fig. 25, takes steam at a pressure of 600 lbs./sq. inch, 800 deg. F., and exhausts at a pressure of 200 lbs./sq. inch to the normal pressure steam system in the station which serves the remaining plant, including the 7,500 kW. unit already mentioned. This latter unit is designed for steam at 200 lbs./sq. inch, 580 deg. F. total temperature, with a vacuum of 28 inches. During 1937 a further order was received for a duplicate set, which is at present in course of completion on site. The first 7,500 kW. unit is shown in Fig. 26, and the new set will be of identical appearance when finished. Both 7,500 kW. turbines are of advanced design in that they incorporate on the rotors discs solid with the shaft for the first seven stages, followed by individually-mounted

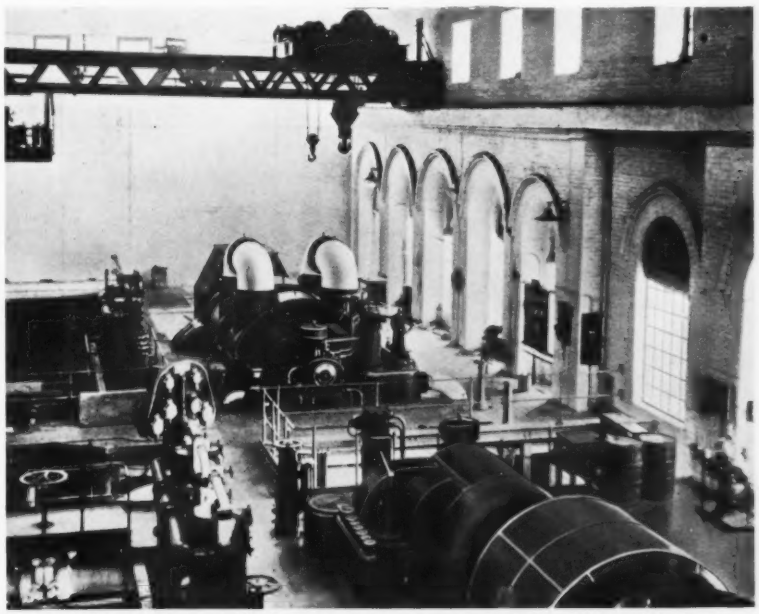


Fig. 21.—15,000 kW. two-cylinder Turbo-alternator set in the Power Station of the Cawnpore Electric Supply Company, Ltd., India, during completion of erection.

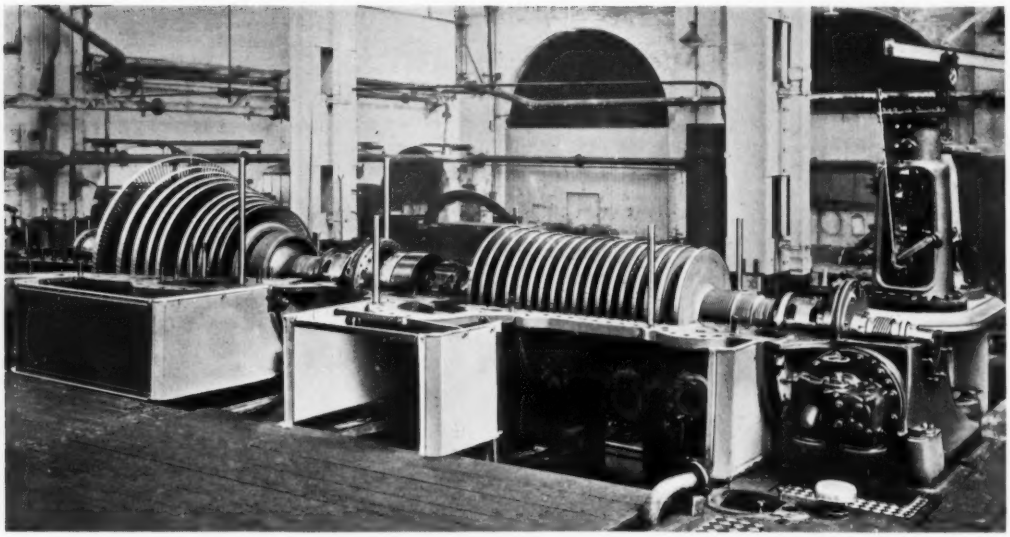


Fig. 22.—The 15,000 kW. two-cylinder Turbine supplied for Cawnpore, during erection at Rugby Works.

discs for the remaining stages. In this way most of the advantages of the Company's standard two-cylinder designs with solid-type H.P. rotors for the high temperature zones, are incorporated in a single-cylinder machine of medium output, while retaining all the benefits of the shorter and less expensive set. The operation of the unit already in service has been very successful, and in the course of six years' service since first set to work, has not once been out of commission for other than normal routine stoppages.

THE SOUTH WALES ELECTRIC POWER COMPANY.

The illustraion in Fig. 27 shows in course of erection at the Company's Rugby Works the turbine of the 30,000 kW. turbo-alternator set ordered last year by Messrs. Edmundsons Electricity Corporation for the Upper Boat Power Station of The South Wales Electric Power Co. During the current year a duplicate set has been ordered for the same station. The turbine in each case is of the two-cylinder impulse-reaction type with inwards double-flow low-pressure cylinder, generally similar to the 30,000 kW. units put into commission this year at Stourport Power Station and illustrated in Fig. 13.

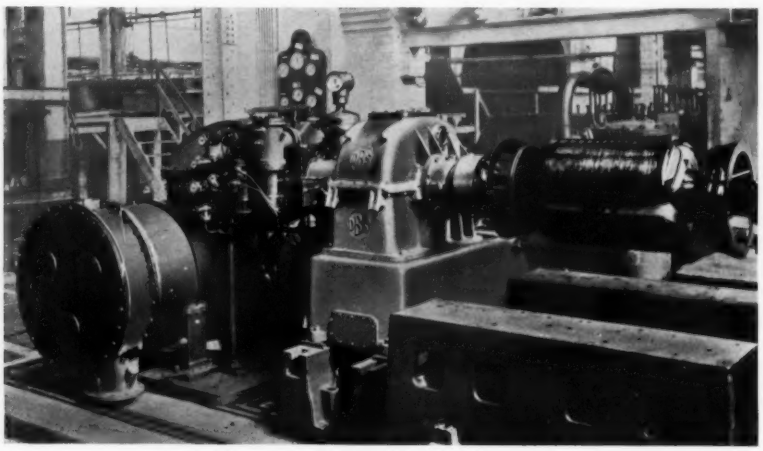


Fig. 23.—1,250 kW. Non-basement Turbo-alternator set for City of Jodhpur, India, during completion at Rugby Works.

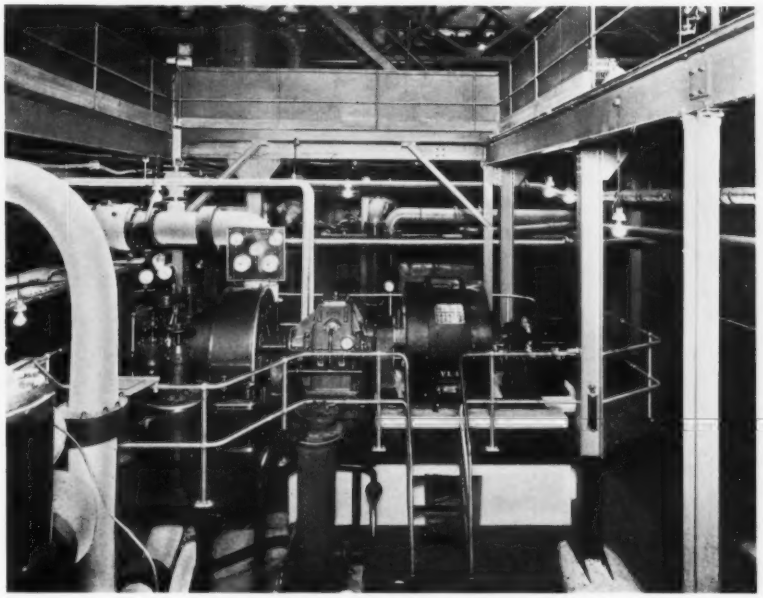


Fig. 24.—800 kW. Back-pressure Turbo-alternator set installed at the Kidderminster Works of The British Sugar Corporation, Ltd.

The turbines are designed for steam conditions of 625 lbs./sq. inch, 825 deg. F. with a vacuum of 29 inches at M.C.R., and the alternators are each designed for 33,000 volts direct generation. These two units, with four turbo-alternator sets previously supplied, bring the total capacity of plant supplied and on order for the Upper Boat Power Station to 106,000 kW.

The general design of the turbines and condensing plants is similar to the units supplied for

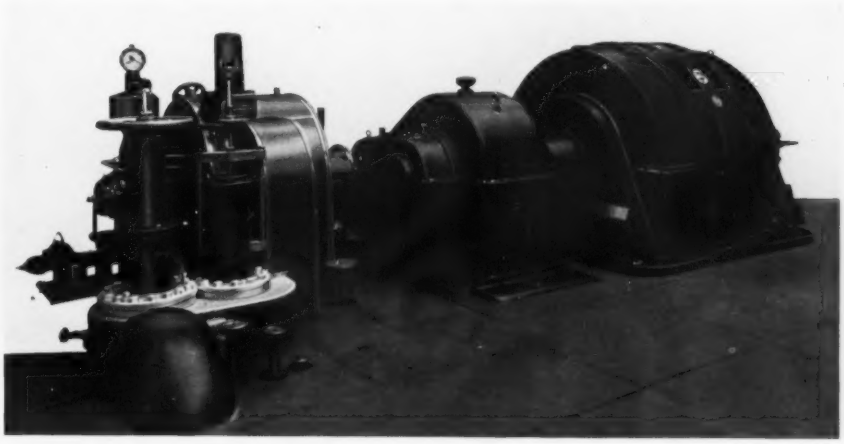


Fig. 25.—2,000 kW. High-pressure back-pressure superposed Turbo-alternator set in the Power Station of the Slough Trading Estates, Ltd.

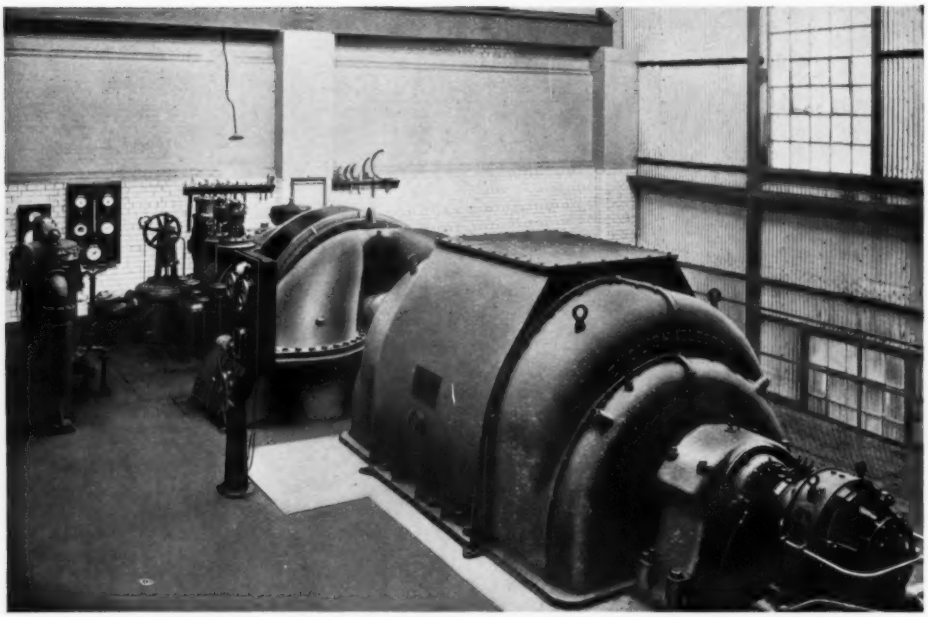


Fig. 26.—7,500 kW. Turbo-alternator set in the Power Station of Slough Trading Estates, Ltd.

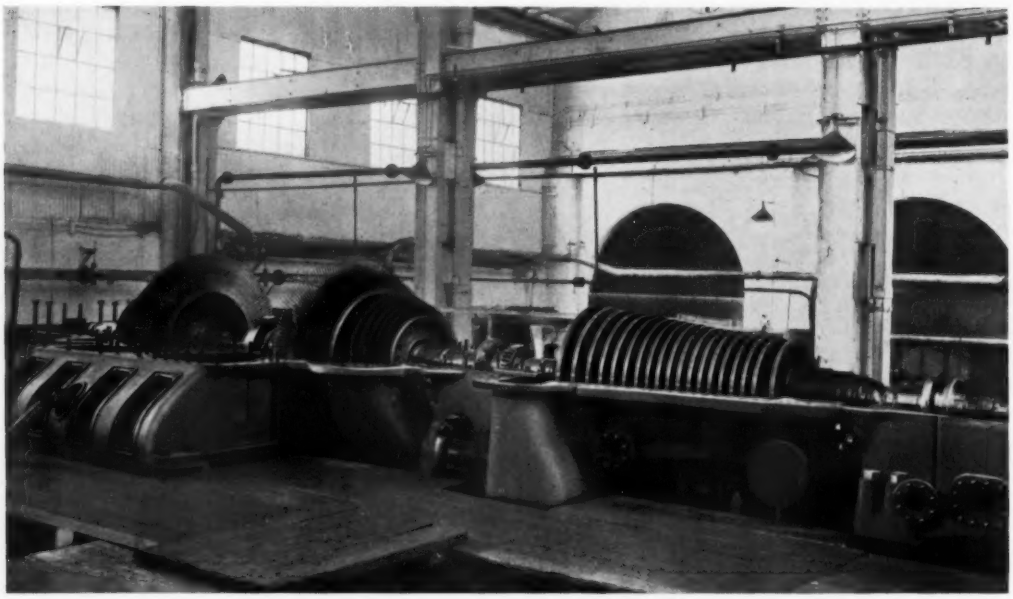


Fig. 27.—30,000 kW. Two-cylinder turbine for the Upper Boat Power Station of the South Wales Electric Power Company in course of erection at Rugby Works.

Fig. 28.—Air Cooler for 30,000 kW. alternator.

Stourport and Ferrybridge, already described. The 33,000-volt alternators incorporate windings of the concentric core design. As with all modern large generating units, the alternators are ventilated on the closed-air system, and Fig. 28 shows the closed-circuit air cooler for the first of the 30,000 kW. sets. It is of interest to note that the air-cooler water boxes are divided so that one half can be shut off on the water side for cleaning purposes while the other half remains in operation, similar to the arrangements incorporated on the condensers, which are of the same design as that illustrated in Fig. 15.

Conclusion.

The foregoing is but a very brief description of the machines and plant covered by the repeat orders for turbo-generating equipment received during approximately the last two years. Although an endeavour has been made to illustrate as many as possible of the improvements which have been incorporated in these latest designs, by far the greater number of what may be termed the improvements of small magnitude but which are equally as important as those described, have of necessity been omitted from this article. It is hoped, however, that the improvements to which it has been possible to refer will serve to convey some idea of the continuous effort constantly being made by the Company to improve on existing satisfactory designs. Without this constant effort and the equally necessary and complementary research and experimental work, progress would be slow, and ultimately cease.

The Malakand Hydro-Electric Scheme.

By H. L. BAZALGETTE, A.C.G.I., A.M.Inst.C.E., A.M.I.E.E.

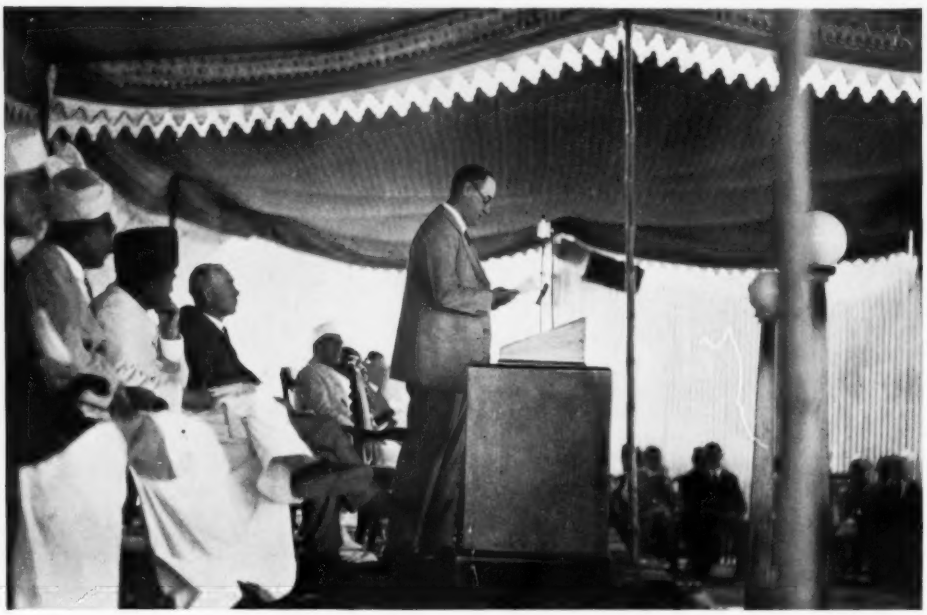


Fig. 1—H.E. the Viceroy delivering his speech at the Official Opening.

On the 23rd April, 1938, H.E. the Viceroy of India, the Marquess of Linlithgow, accompanied by Sir George Cunningham, Governor of North-West Frontier Province, and Dr. Khan Sahib, the Premier, was present at the opening of the Malakand Hydro-Electric Scheme and, by closing a switch, started up the turbines and thus signalised the completion of the first important work executed by the Province since it achieved autonomy.

Fig. 1 at the head of this article shows His Excellency making his speech at this interesting ceremony.

The power station lies in a district rich in historic interest in connection with past frontier campaigns and a supply of electricity is now available to the towns and cantonments bearing the well-known names of Dargai, Mardan, Nowshera, Peshawar, Charsadda and Risalpur, with the likelihood of early extension to other centres.

The difficulties met with in the execution of a scheme of this nature in a remote and mountainous district subject to earthquakes, dust storms and extreme variations in temperature and not devoid of danger from hostile tribesmen, cannot be exaggerated, and the Public Works Department are to be congratulated on a very notable achievement. Some idea of the nature of the country can be obtained from the frontispiece showing the power station site, and from Figs. 2 and 3

Fig. 2—The Khyber Pass.

which show views of the Khyber Pass in the immediate neighbourhood.

It is gratifying that the English Electric Company was able to take a prominent part in this work and, by the successful completion of its contract comprising the pipelines, valves, water turbines, generators and haulage gear, the Company again demonstrated its ability to execute comprehensive hydro-electric contracts in any part of the world and under the most exacting conditions.

Layout of the Scheme.

The possibility of generating electricity at Malakand was first recognised some 25 years ago by the irrigation engineers of the Punjab, of which the present North - West Frontier Province was then an outlying district, and it was seen that the waters of the Swat River to the north of Malakand could be used for fertilising the north-eastern part of the Peshawar Valley by driving a tunnel under the Malakand Pass and by constructing a canal. The tunnel, known as the Benton tunnel, was duly completed and it was evident that by extending it another half mile to a point above the Upper Swat Canal advantage could be taken of a natural fall of some 250 feet for the production of electricity. The scheme was sanctioned in 1934 and the new tunnel 12 feet in diameter, which was called the Burkitt tunnel after Mr. F. H. Burkitt, C.I.E., Chief Engineer to the North-West Frontier Province, was put in hand, the construction being undertaken by local labour and without the aid of machinery.

The hydraulic works provide for an ultimate installation at the Jabhan Power House below Malakand Fort of six generating units, but for the first stage only three sets each 3,200 kW. have been installed.

The power is generated at 11 kV. and stepped up to 66 kV. and transmitted 30 miles by a double circuit line to Mardan and thence by single circuit line for a further distance of 74 miles to Charsadda, Risalpur, Nowshera and Peshawar Canton-

Fig. 3—Camel train in the Khyber Pass.

Fig. 4—Forebay, Penstocks and Haulage Way.

ments. Substations for 66 kV. have been established at four important centres and 11 kV. branch transmission lines totalling 37 miles, with nine 11 kV. substations at convenient points, constitute the distributing system.

The scheme had the advantage of the initial load available in the area at the numerous military establishments which in turn benefitted by receiving a cheaper supply and by being able to shut down numerous small plants. It is anticipated that a supply of electricity at low cost will lead to the development of natural resources and the creation of industries within a Province which is remote from other sources of energy such as coal and oil. In addition the scheme, when fully developed, will materially benefit the Province by increasing revenue and providing a high return on the capital expended.

The English Electric Company's Contract.

The main contract for the generating plant was placed with this Company in January, 1936, and comprised three 4,500 h.p. water turbines and generators, main inlet valves, penstock pipelines and forebay valves, trash racks, haulage gear, etc. It was, therefore, of a comprehensive and important character embracing the whole of the equipment from the forebay down to the generators.

At the tail of the Benton tunnel referred to above the water is discharged over a regulating weir into the new power tunnel which runs parallel to the Dargai Nullah (formerly carrying the water from the Benton tunnel exit to the Upper Swat Canal System) until a difference in level of 250 feet is obtained down to the nullah bed. Here the water emerges from the power tunnel into an open channel and forebay and thence via penstock pipes to the power house. At the power tunnel exit there is a stilling pond which reduces the velocity of the water causing the deposition of silt which gradually moves forward and is drawn through vents in the channel below and removed automatically.

In the open channel there is a waste weir and spillway syphon, the function of the latter device being to allow evacuation of excess water automatically, in the event of sudden closure of the turbines, with only slight fluctuation in the level upstream.

Pipelines.

The three penstock pipes connecting the forebay to the three turbines were supplied by Messrs. Stewarts and Lloyds, Ltd., under a sub-contract, and are each 515 feet in overall length. They are in two sections, a top section running between the forebay and a concrete anchor block, and a lower section between the anchor block and the power station. The pipes comprising the top section are 61 in. external diameter and $\frac{1}{2}$ in. thick and those of the bottom section are 55 in. external diameter and $\frac{9}{16}$ in. thick. The pipes are in 26 ft. lengths with longitudinal seams hydraulic roller lap welded by the watergas process. Double riveted bump joints are adopted throughout except at and around bends, at valves, and at terminal ends where welded flange joints are used. Expansion joints are provided for each section of pipe between anchor blocks. The pipelines were designed for a maximum static head of 250 feet (approx. 108 lbs./sq. in.) and for a test pressure of 115 lbs./sq. in. on the upper section between the forebay and the middle anchor block, and of 195 lbs./sq. in. on the lower section.

Each pipeline is provided with a trash screen consisting of flat steel bars $2\frac{1}{2}$ in. by $\frac{3}{8}$-in. with 2 in. spacing to protect the turbines from débris.

Haulage Gear.

Also included in the Company's contract was the haulage gear for the pipeline haulage way which can be seen in the frontispiece and in Fig. 4. This haulage way which is of metre gauge was not only indispensable during construction for the erection of the pipeline sections but is also now very useful as a means of access between power station and forebay and for conveyance of loads between the two points. The gear, which was supplied by Messrs. Hatfield, Perrin & Partners under a sub-contract, consists of an electrically driven haulage winch to haul a total load of $6\frac{3}{4}$ tons up a maximum incline of 32° 16′ at a speed of 50 ft. per minute, together with a four-wheeled truck and wire rope guaranteed for an actual breaking load of 30.7 tons.

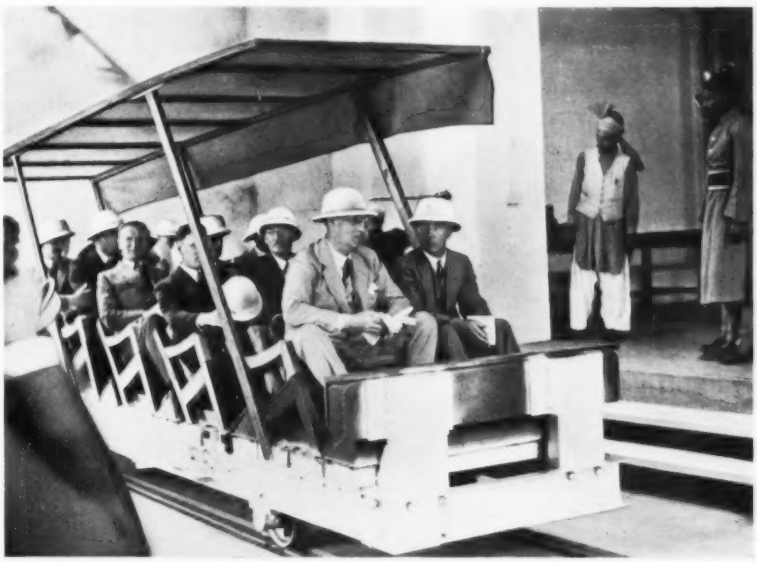


Fig. 5—H.E. the Viceroy seated in the Haulage Way truck.

Fig. 5 shows H.E. the Viceroy seated with Sir George Cunningham in the front of the truck before proceeding up the haulage way to inspect the forebay works.

Forebay Valves.

Located in the forebay are three balanced disc butterfly valves of the self-closing type, 60 in. internal diameter, supplied by Messrs. de Roll, of Klus, Switzerland.

The valve door is operated by weights mounted on arms attached to the door spindle, an oil-dashpot prevents slam shutting, and a hand-gear allows of the re-raising of the weights after operation.

The tripping gear is of the usual paddle trip type, and is designed to operate at varying excess velocities.

Turbine Inlet Valves.

At the turbine inlets are provided " English Electric " streamline cylindrical balanced valves of the Company's well-known patented type. These valves, which are 42 in. bore, are designed to obtain complete security for the turbine plant and therefore, fulfil a very important function in the whole installation. This type of valve has been described many times in this Journal, but it may be useful to recall the following features which render it certain of satisfactory operation under both normal and emergency conditions :—

(1) The valve piston, which is a cylinder and thus remains always balanced, requires only a small force to move it and is inherently free from distortion and jamming.

(2) The operating servo-motor directly surrounds the piston and has a very large margin of power.

(3) The travelling control screw, which is an especially interesting and effective device, in combination with the balanced cylindrical piston makes water hammer an impossibility. The screw moves with the piston and by this means obliges the pressure water supply to the servo-motor to traverse an ever increasing number of screw threads as the closing stroke is performed. The last part of the piston movement is, therefore, very slow and this prevents pressure rise, but not at the expense of the total closing time which remains reasonably short.

(4) The careful streamlining of the valve ensures that there is no obstruction to the flow.

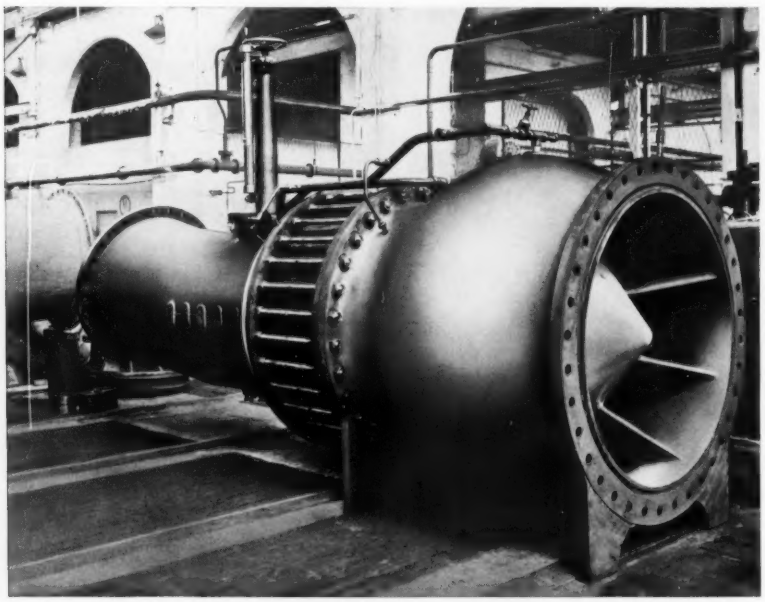


Fig. 6—Cylindrical Balanced Turbine Inlet Valve at Works

The main parts of the valve are made of cast iron with rust protection where necessary. Fig. 6 shows one of the cylindrical balanced inlet valves assembled at Rugby Works.

Power House.

The Power House containing the generating plant occupies a site on the west bank of Dargai Nullah, immediately below Malakand Fort, and lies at an altitude of 1,750 ft.

All consignments of plant were taken by train from Karachi to Dargai railway station, a distance of about 1,000 miles, and thence transported by lorry over an old Buddhist road by which Alexander the Great invaded India. The power house and its surroundings are shown in the frontispiece and the buildings comprising Malakand Fort can be seen at the top of the picture.

It will be noted that the forebay works have been arranged to accommodate another three pipelines in the future.

On the left of the picture is the step-up transformer station which is connected with the power house by a bridge over the spillway channel; this channel receives the spill nullah which can be seen descending the hillside to the left.

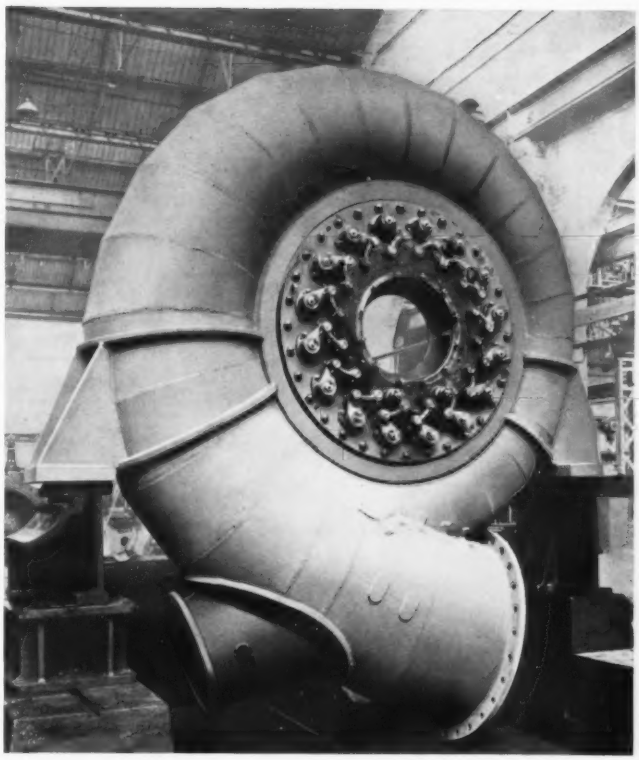


Fig. 7—Turbine Spiral Casing with swivel gate levers and links.

The power house contains three horizontal reaction water turbines each capable of a full load output of 4,500 b.h.p., an overload output of 4,750 b.h.p. when running under a net head of 243 feet and at a speed of 600 r.p.m. The turbines drive three 3,200 kW. 3-phase alternators designed for 0.85 power factor lagging, 11,000 volts, 50 cycles and fitted with main and pilot exciters. Plates Nos. I and II show cross sections through the Turbine and Alternator respectively.

Turbines.

The turbines are of the overhung type having no shaft or bearings of their own, the runners being fitted to the ends of the generator shafts. This compact construction is now practically standard for the Company's horizontal units since it is a product of that close co-operation between mechanical and electrical designers which the Company is able to secure by virtue of the fact that it manufactures both ends of the combined unit.

The spiral casing, which is shown assembled at the Company's Rugby Works in Fig. 7, is of the usual logarithmic form and is fabricated from mild steel plates graduated in thickness from $\frac{1}{2}$ in. to $\frac{3}{8}$ in. It has an inlet diameter of 42 in., and is practically circular in cross section in order to prevent distortion under pressure, with butt joints between segments and double-welded lap joints where it joins the speedring, the plates fitting inside the speedring flanges.

The speedring is made of fabricated steel bridging the throat gap of the spiral casing and consists of two massive forged steel guide rings rigidly tied together by strong nickel-steel stays.

Strong bracket feet are provided on the casing

and these are bolted down to the combined bedplate of the unit. A branch is provided for connection to the relief valve. In order to obtain a rigid setting the bottom part of the casing and the bedplate are drowned in concrete.

The gate apparatus consists of a set of swivel gates of stainless steel cast integral with their stems which are protected by special collars. When closed the gates make contact with each other along machined bearing strips so that leakage is reduced to a minimum. The swivel gates are coupled by cast iron levers and links to a regulating ring sliding on gun metal pads and connected by adjustable gear direct to the governor. The connecting gear between gates and ring is " offset " so as to reduce the regulating energy by making the quantity of water shut off or admitted by the gates generally proportional to the governor stroke. Should an obstruction prevent one of the gates from following the regulating ring, the links are designed to break well before the elastic limit of any more important part of the apparatus is reached. These links are a cheap and simple spare part which are easily renewable in service.

In the event of a gate becoming uncoupled the design is such that it cannot foul any of the other gates or the runner. To permit of adjustment to every individual gate both in the shops and in the field, each link is fitted with an eccentric pin and, by turning and then locking the latter, the distance between pin centres (i.e., the effective length of a link) can be varied and a gate can be shifted as desired. Fig. 7 shows the regulating gear assembled on the spiral casing at Rugby Works.

The turbine main cover carries the regulating ring and gland and is of strong box construction. It contains passages for the evacuation of any leakage water passing through the runner seals, and these lead to a pipe discharging into the tail race. By this means water will not be trapped in the space between runner crown and cover and the hydraulic end-thrust on the wheel will be reduced, especially at runaway. Although reduction of hydraulic thrust is, therefore, inherent in this design, additional security is obtained by providing a Michell thrust block in the inboard generator bearing.

The shaft gland is cooled by filtered water and is well lubricated; packing rings of special material which does not react on the metal are used.

The turbine runner is made of high-grade stainless steel carefully streamlined, ground and polished. As the turbines have to operate at an altitude of 1,750 feet above sea level and run at a speed of 600 r.p.m., the question of security against cavitation required careful study. This security was attained by adopting liberal dimensions for the runner so as to reduce the velocity of the water passing through it and, therefore, the dynamic suction at the outlet of the vanes, and by the provision of the minimum number of vanes in order to occupy less room in the water stream. The vanes and the passages between them were also carefully streamlined and the use of stainless steel with all surfaces worked smooth afforded a further safeguard.

The seal with the turbine guide wheel covers is effected by means of brass rings hammered into groves in the crown of the runner, the brass being a soft material is worked down to the exact bore of the covers leaving only a fine running clearance. Thus there is very little leakage.

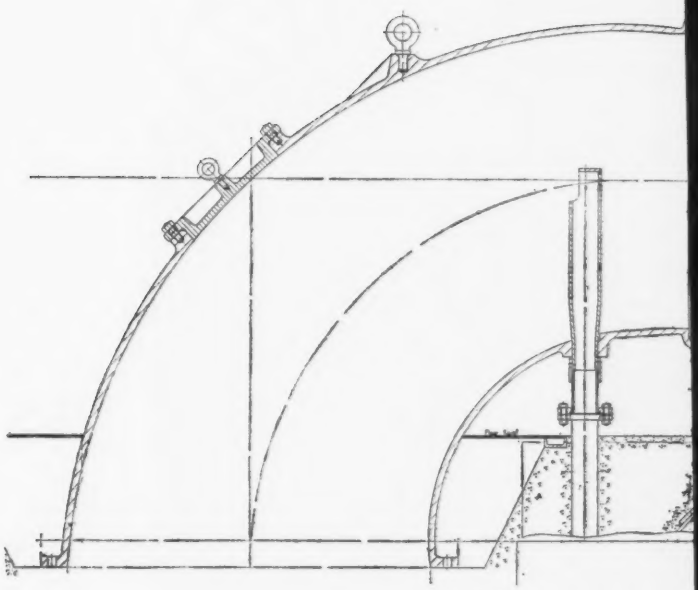
To relieve the pipeline and avoid excessive pressure rise due to load fluctuations the turbines are provided with cylindrical balanced streamline relief valves. These are so connected to the spiral casing that they form a continuation of the pipelines and the water passes smoothly into the tailrace without causing chattering or erosion.

The design is very similar to that of the cylindrical balanced inlet valve embodying a balanced piston requiring only a small force for operation and it thus moves smoothly and in exact synchronism with the rapid turbine gate closure.

The central cone of the inner body of the relief valve causes the rapid dissipation of the energy of the incoming water in the form of a fine spray, a particularly valuable feature in the present case owing to the narrow channel into which the water has to be discharged.

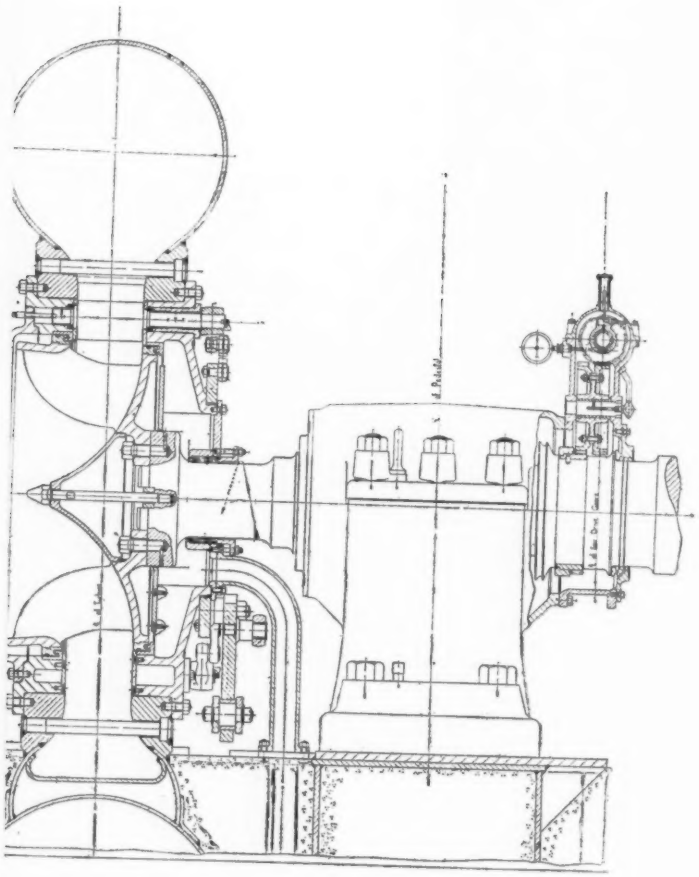
The governor is of the Company's standard oil pressure type, the actuator being driven from the main shaft by means of a flexible gear drive.

THE MALAKAND HY

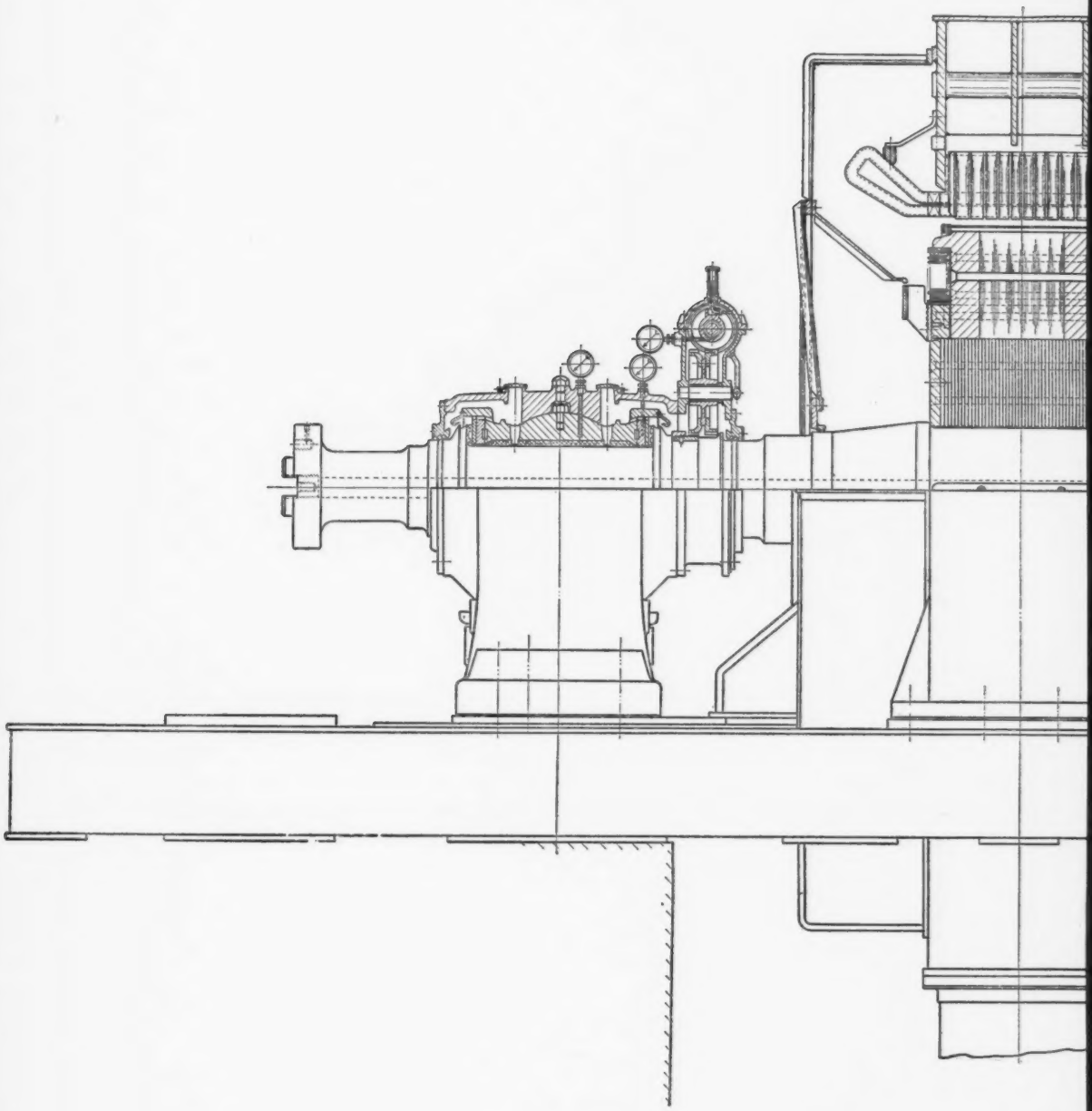


Cross Section through 4,500 H.P.

DRO-ELECTRIC SCHEME

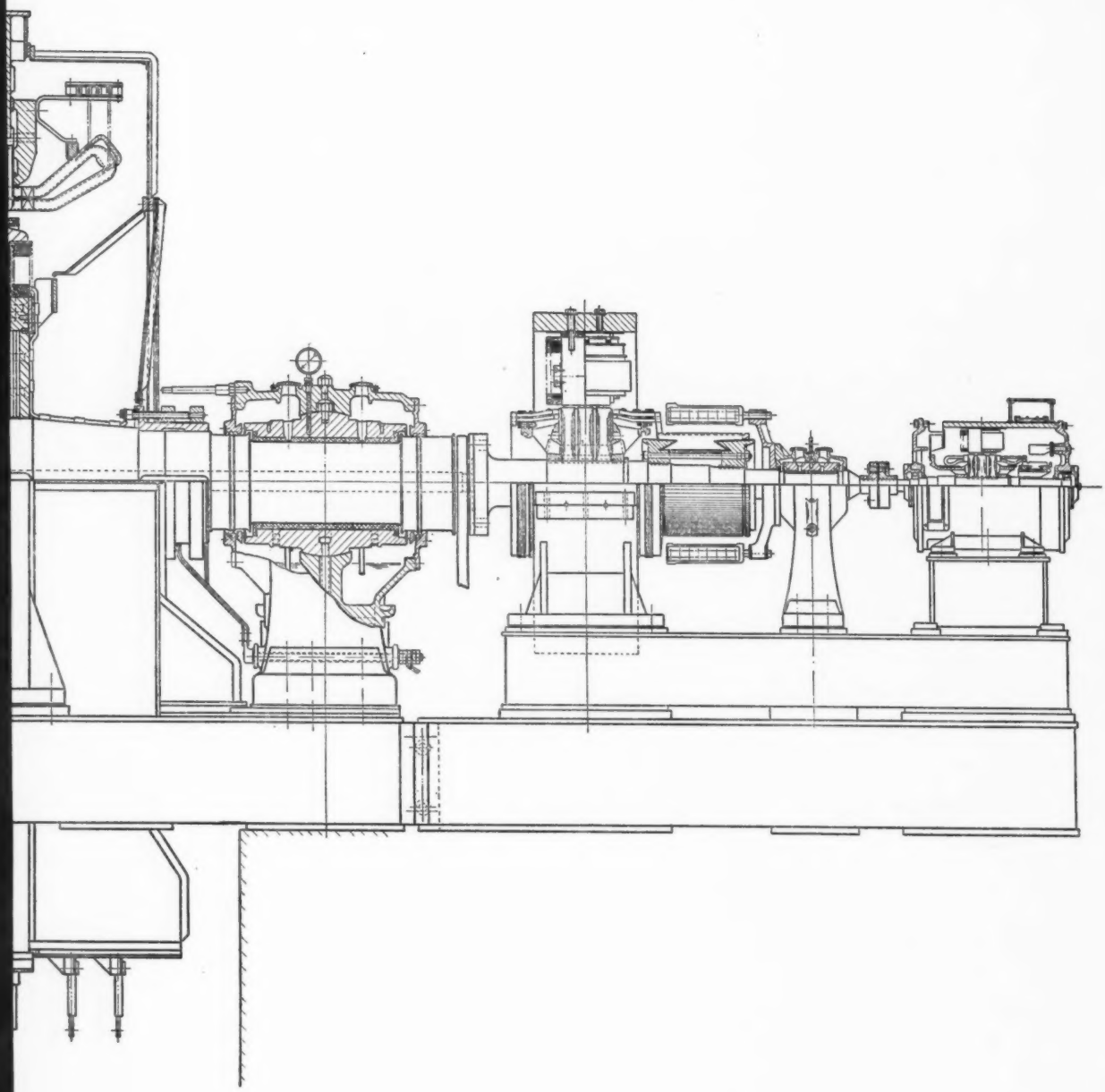


Horizontal-Reaction Water Turbine.



Cross Section through 3,200 kW

DRO-ELECTRIC SCHEME



Water Turbine-driven Alternator.

PLATE II.

[The English Electric Journal.

Fig. 8—4750 H.P. Set in Power Station showing governor gear.

The governing equipment which has been described in detail on former occasions, is shown in Fig. 8. The turbine gates are opened and closed by a regulating ring which, in turn, is operated by a regulating shaft connected to an oil servomotor which can be seen in the foreground.

The servomotor cylinder contains a double-acting piston, and a handgear and clutch is provided for manual control when desired. The servomotor receives its pressure oil at 180 lbs./sq. in. from an oil pump driven by an electric motor which can be seen to the right of the generator in Fig. 10. Beside the oil pumping set is the oil-pressure receiver, the function of which is to act as a pressure reservoir and to maintain the oil pressure at its correct value. Safety and bye-pass valves are provided. Mounted above the servomotor is the governor actuator which has been well described as the " brain " of the whole plant.

This, as already stated, is driven from the main shaft by means of gears and a horizontal shaft which can be clearly seen in Fig. 8. This shaft drives a pendulum within the actuator which operates a distributing valve and thus controls the pressure oil to the servomotor. Incorporated in the mechanism is a safety device to close the turbine in the event of overspeed, oil pressure failure or underspeed, with an auxiliary contact to open a tripping circuit and thereby cause the complete shut-down of the unit. The tripping circuit can also be opened and the set shut down from the switchboard. A neat instrument panel is provided for the pressure and vacuum gauges.

The governing system was subjected to rigorous and extensive tests before shipment and the whole equipment was erected on site

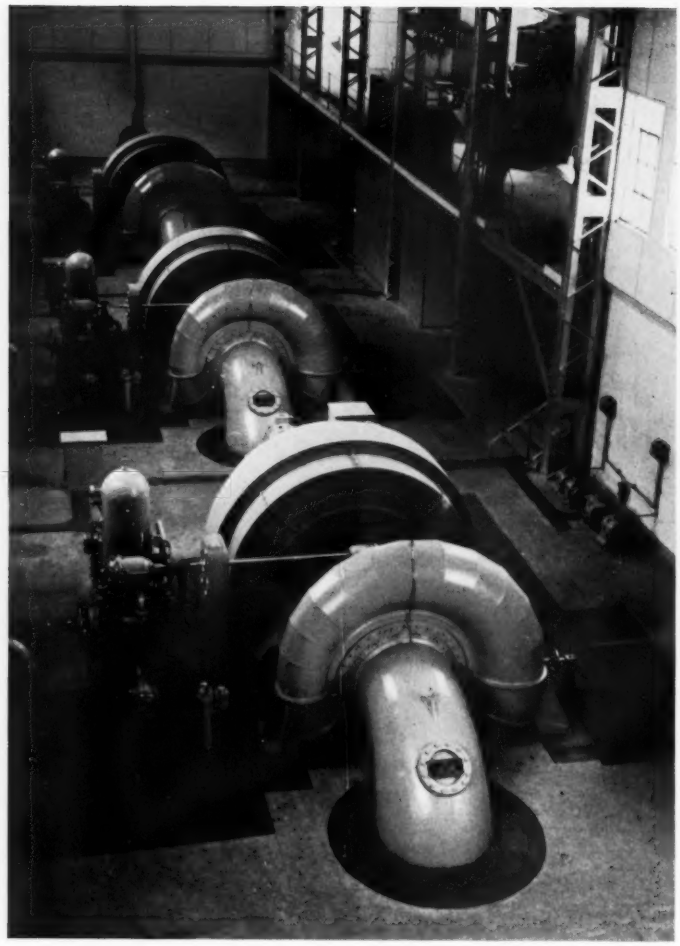


Fig. 9—Three 4750 H.P. Sets in the Power Station viewed from turbine ends.

and put into service with the minimum of adjustment.

ALTERNATORS.

The alternators have a maximum continuous rating of 3,760 kVA. and are designed for a normal speed of 600 r.p.m. and a runaway speed of 1,100 r.p.m. They are wound for 3-phase, 11,000 volts normal, 50 cycles. The machines have horizontal shafts running in two main bearings and each machine has a main exciter and a pilot exciter with a bearing between the two. The machine is mounted on a fabricated steel bedplate and the exciter rests on a separate bedplate bolted to the main bedplate.

The alternator frame is of welded steel construction in a single piece and has sufficient depth of section to ensure an adequate volume of ventilating air which is discharged into it and thence to a discharge duct in the foundation via a bottom chimney.

The stator winding is of the two-layer or basket-type with Class " B " insulation throughout, all coils being alike and interchangeable.

Well-seasoned impregnated hardwood wedges retain the coils in the slots and the end part of the winding is fixed in position by hardwood blocks between coil limbs which are lashed back to mica-insulated support rings bolted to the stator endplates.

This type of winding is especially suitable for withstanding surges and the forces set up on short circuits.

In order to eliminate as far as possible harmonics from the terminal wave pressure, advantage is taken of the possibility of using a fractional number of slots per pole combined with a short pitch to obtain a balanced symmetrical 3-phase winding.

Copper constantan thermo-couples are embedded in the stator winding to give an indication of the temperature at various points. These are connected to a terminal box on the stator frame and a suitable indicating instrument with motor-driven selector switch is provided to connect in circuit each thermo-couple in turn, thus giving an alarm if the temperature of any one exceeds a predetermined value.

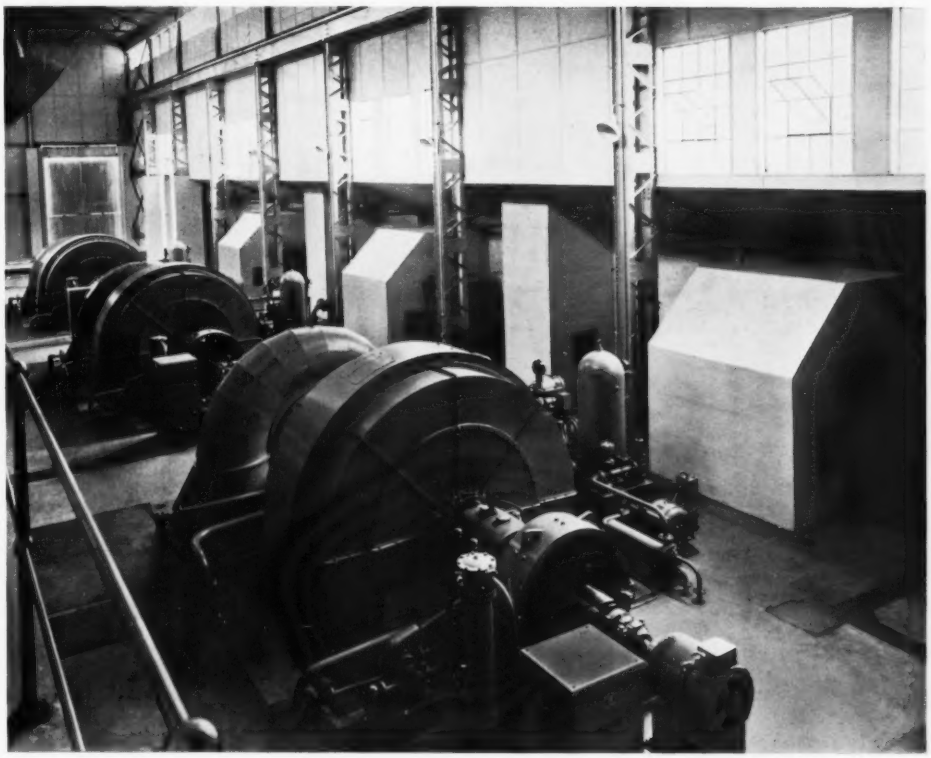


Fig. 10—Three 4750 H.P. Sets in the Power Station viewed from generator ends.

The rotor body is shrunk on the shaft and is built up of $\frac{1}{2}$ in. rolled-steel plates clamped by rivets between end plates. The solid body thus formed is machined and dovetails are cut in the periphery to receive the poles, which are built up of laminated steel stampings.

In order to obtain satisfactory parallel operation and ensure stability on the system under disturbances caused by high and low-frequency transients, the pole faces are provided with a damper winding consisting of copper rods in semi-closed slots brazed into copper short-circuiting end-segments. The field coils are formed of copper strip wound on edge mounted on sheet-steel spools, the insulation being Class "B" throughout and mica insulation being provided between turns and to earth.

The machine is ventilated by the provision of a fan at each end of the rotor and air is drawn in at both ends from the pit through sheet-steel trunks secured to the end-shields. The rotor fans and the fanning action of the pole forces the air through radial ducts in the stator core and a portion of the air is bye-passed across the end-windings. The discharged air passes circumferentially round the stator frame and is discharged through a bottom chimney to a discharge duct in the foundations. A viscous air filter is provided in the inlet and electrically-operated dampers are provided in both inlet and outlet ducts to stop the air circulation in case of emergency.

The main bearings are of the self-aligning, spherically-seated type provided with forced oil lubrication from an oil pump belt-driven from the main shaft, the oil being passed through an external oil cooler.

The double thrust bearing, of the Michell type

Fig. 11—Mixing concrete with water poured from goatskin vessel.

designed to deal with a thrust of 24 tons, is cooled by means of the circulation of oil from the same pump which can be seen in Fig. 10. In each bearing is provided a dial type thermometer with contacts to operate an alarm should the temperature exceed a predetermined value.

An overspeed device of the centrifugal type is incorporated in the turbine governor gear drive, the fixed portion being carried from the gear case and the moving portion on an extension of the governor shaft.

The direct-coupled main and pilot exciter armatures are mounted upon the same shaft, the latter exciter being of the overhung type.

Fig. 12—Generator stator arriving at site.

Owing to the extensive overhead transmission system ultimately to be supplied, it was necessary for the alternators to be designed to have quick response excitation which, operating in conjunction with automatic voltage regulators, enables the voltage over the whole network to rise with increase of load. The machines are, therefore, designed for stable operation from the limits of 3,000 kVA. zero leading power factor

Fig. 13—A typical group of Native Workmen employed by the Company.

9,800 volts up to a maximum of 3,200 kW. at 0.85 lagging power factor 12,100 volts. Between the limits of no load and full load the increase in the alternator terminal voltage is 10 per cent., i.e., from 11,000 volts at no load up to 12,100 volts at full load. Furthermore, the range of operating terminal voltage can also be lowered to 9,800 volts at 3,000 kVA. zero power factor leading, rising to 10,780 volts at full load.

The ceiling voltage is such that the rate of exciter response in volts per second is twice the numerical value of the excitation voltage corresponding to 3,200 kW. (i.e., full load) 0.85 power factor, a current limiting resistance being automatically inserted to limit the steady field current to twice full load value.

Automatic Features.

A number of automatic devices are provided with the plant. The butterfly valves at the forebay are fitted with an electrically-operated trip; the cylindrical balanced valves can be opened and closed electrically, and the turbines can be shut down electrically by means of a solenoid on the governor. The automatic features are interconnected and controlled through limit switches and tripping devices for a comprehensive control scheme which is now a common feature of the Company's turbines and associated hydraulic plant.

Erection.

The erection of the plant proceeded smoothly considering the difficulties which were bound to be encountered in a region so remote.

Fig. 11 shows a somewhat primitive method of mixing concrete which was being employed when our erecting engineer first arrived at site. It will be noted that the supply of water is from a goat-skin vessel.

Fig. 12 shows the packing case containing the generator stator arriving at site, and Fig. 13 is a typical group of some of the Company's native workmen.

As stated at the commencement of this article the scheme was formally inaugurated by H.E. the Viceroy on 23rd April, 1938, and according to reports received from India the plant is operating satisfactorily on the load at present available.

New Developments in Low-Pressure Blading for Steam Turbines.

By J. P. CHITTENDEN, M.I.Mech.E., A.M.I.E.E.,
Chief Engineer and Manager, Steam Turbine Department.

There are many problems in connection with the design and construction of the long blades at the low-pressure end of steam turbines of large output, and in a previous issue of this Journal* the problem has been dealt with from the mechanical standpoint. In the article referred to various methods of blade fixing were described, in particular the " English Electric " side-entry root. The design and construction of this method of attachment enables the longest blades now in use to be carried with comparatively moderate stresses, and furthermore it can safely be applied to still longer blades if and when occasion arises.

Another aspect of the problem on which the Company has been working for many years is the efficient guiding of the steam flow through these very long blades. In a short blade the height and width are of the same order of magnitude, and the disturbing influences of centrifugal force on the steam particles have therefore little effect. Furthermore, in short blades the circumferential speed of the blade does not vary appreciably between the root and the tip with the net result that the efficiency is approximately the same over the entire length of blade. The long blade, however, is a very different proposition, as due to the influence of certrifugal forces the steam acquires an appreciable radial velocity which adversely affects the axial flow. In addition, the blade speed varies considerably from root to tip, and clearly a blade of uniform section designed for a given efficiency at its mean diameter will have an appreciably lower efficiency both at the root and the tip.

The English Electric Company has for many years employed blades of spiral or " twisted " section in order to minimise the loss of efficiency inherent in a straight blade of considerable length, and this work has now been carried a stage further by the introduction of what is known as the " English Electric " Vortex blading.

In this type of blading the rotor blade is not only of spiral or " twisted " section but is made with flow angles which decrease considerably from root to tip of the blade, and the degree of reaction also varies, being small at the root section and large at the extremity of the blade. It is well known that for a given ratio of blade speed to steam speed there is a degree of reaction which gives the highest efficiency, and in Vortex blading this reaction is adjusted to suit the blade speed which prevails at each section, and thus the velocity diagram varies progressively along the blade, having at every point a shape which gives the maximum efficiency and the minimum leaving loss.

It will be appreciated that a degree of reaction which varies along the length of the blade naturally entails a varying pressure in the space between the fixed and moving blades of each expansion. The pressure is low at the root section and high at the extremity of the blade near the casing. The pressure variation is approximately that corresponding to a free vortex, and therefore balances the centrifugal forces acting on the steam. Each particle of steam thus follows a helical path, and the undesirable radial flow is avoided.

The " English Electric " Vortex Blade, therefore, unites two valuable features. There is promoted a steady flow with only so much radial component as is necessary to enable the steam to follow the conical path between casing and rotor, since the centrifugal forces are automatically balanced, while at the same time it is automatically ensured that at every section the degree of reaction is correctly adjusted for the blade speed and gives the highest efficiency of which turbine

* *See F. J. Cowlin, "The 'English Electric' Optimum Blade for Steam Turbines of Large Outputs," The English Electric Journal, December, 1937.* (*Vol. VIII. No. 8*)

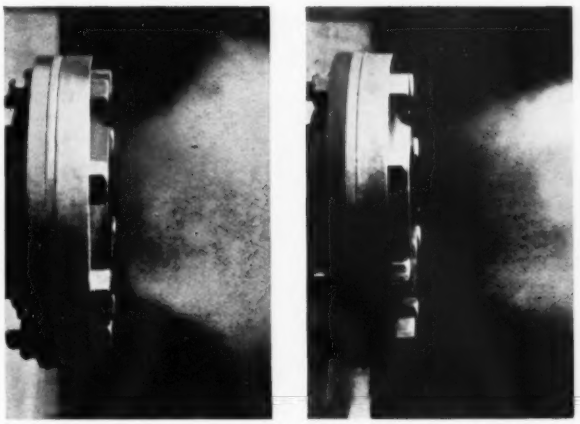


Fig. 1.—Form of discharge with experimental blade rings—on left, normal blading, and on right, normal Vortex-type blading.

blading is capable. This is a considerable advance over the normal "twisted" blade, which can achieve maximum efficiency at only one point of its length and which furthermore cannot prevent undesirable radial flow.

Much experimental work has been carried out by The English Electric Company in this direction, and the work is still proceeding. A more detailed account of the theory of Vortex blading will be presented in the near future when the programme of research work is completed. In the meantime, the results of one of the earlier experiments may be of interest.

The photographs in Fig. 1 show the type of flow obtained from two designs of blading arranged in an annular ring discharging steam into free air. The blade ring shown on the left is designed to give a constant flow angle all along the length of the blade, while that on the right is fitted with Vortex blading. The two blade rings are otherwise similar and were operated under identical conditions, discharging the same weight of steam per hour. It is very noticeable that the Vortex design gives a much more compact discharge, and turbulence does not take place until some distance from the discharge edges of the blades.

Fig. 2 is a photograph of one of the numerous models of Vortex blading made during the preliminary research work on this subject, from which illustration the change of blade section from root to tip can be readily seen. In conclusion it may be said that all the experimental work and investigations that have been carried out in this direction clearly indicate that with the Vortex principle improved efficiencies can be realised with the long blades at the exhaust end of steam turbines, and combined with the side-entry fixing still greater outputs at the higher speeds can be obtained without sacrifice in either efficiency or reliability.

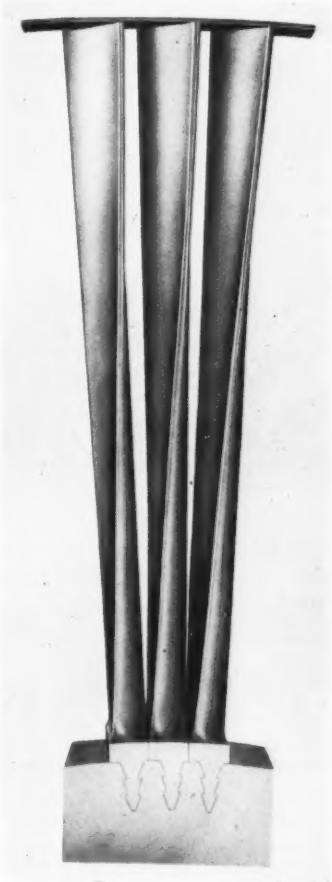


Fig. 2.—Model of Vortex-type Blading.

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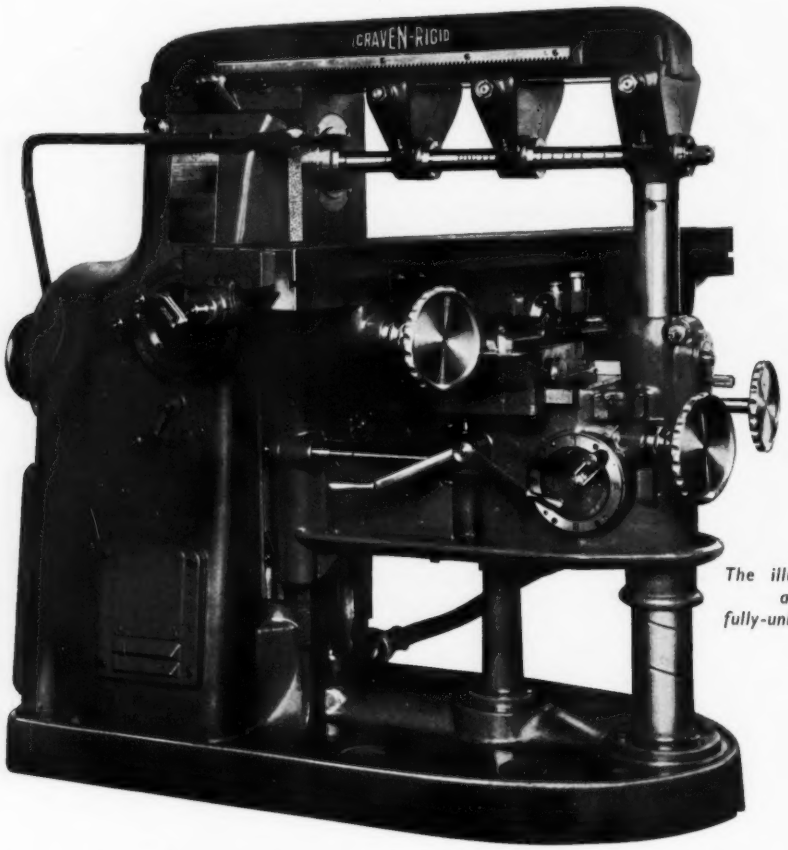

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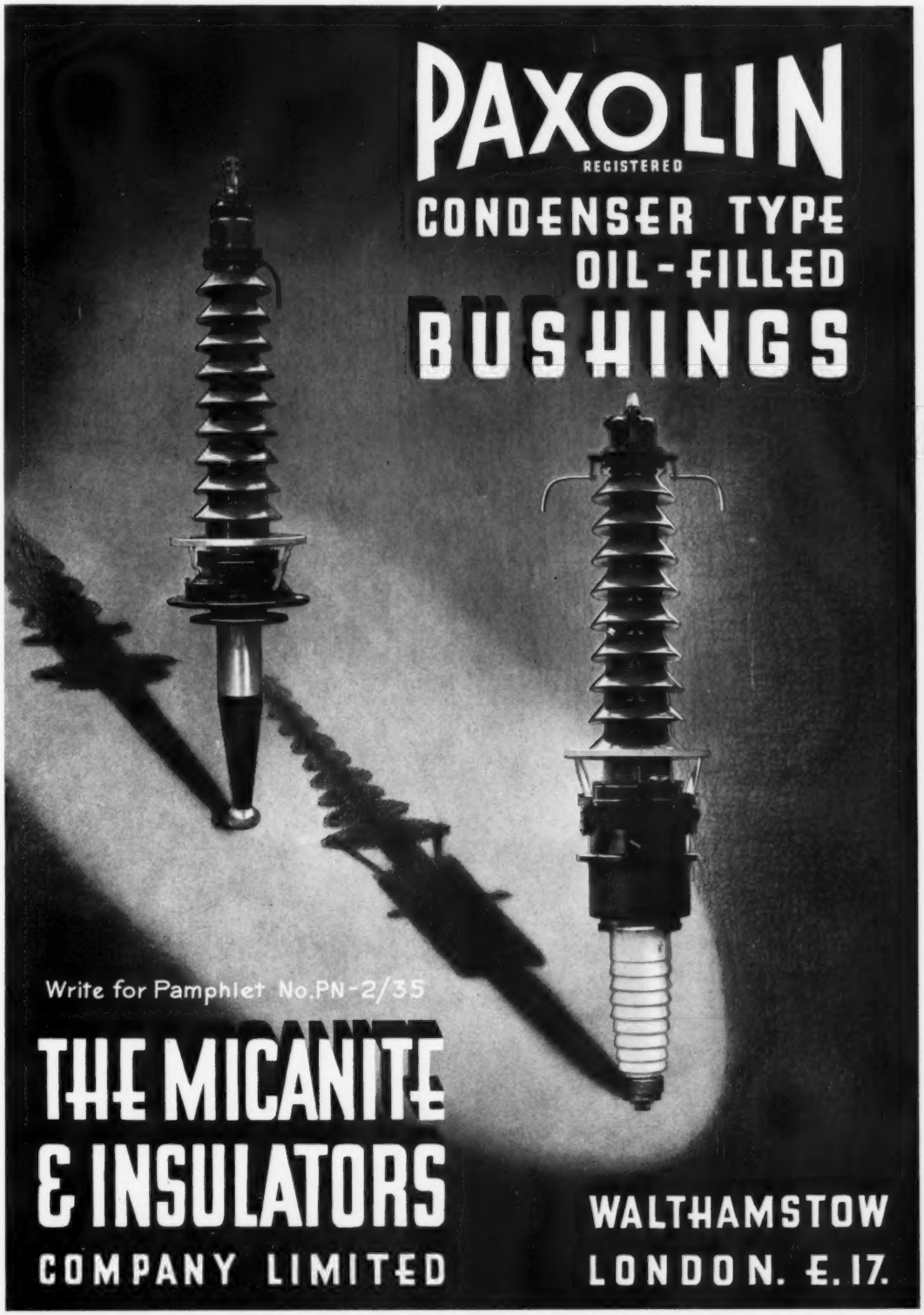
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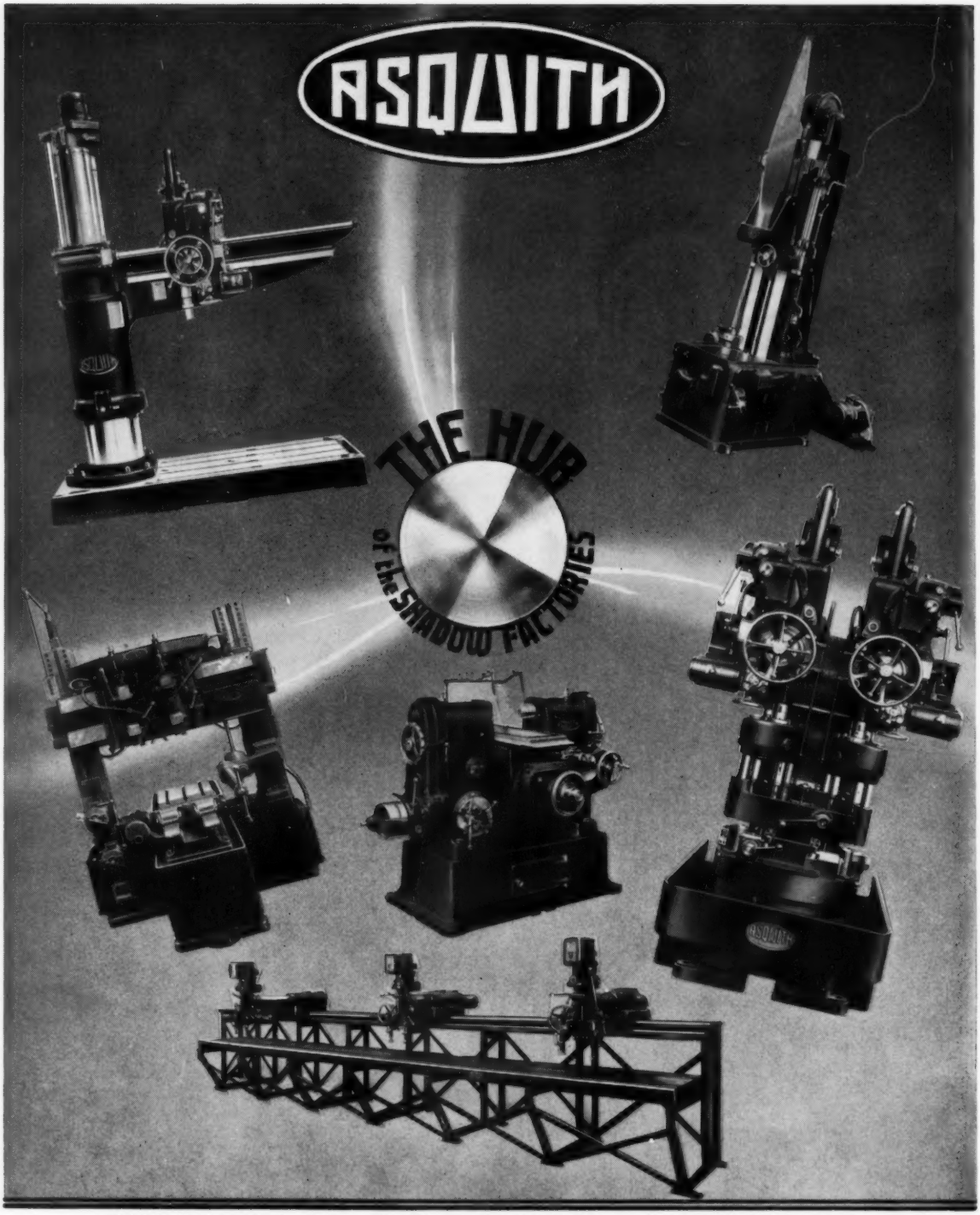

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